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Rockwell International
Mewbury Park, California

February 1976

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RAPS EMISSION INVENTORY HANDBOOK

Volume 1

[Task Order No. 37]

by

Rockwell International
Air Monitoring Center
Newbury Park, California 91320

Contract No. 68-02-1081

Project Officer

Francis A. Schiermeier
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U.S. ENVIRONMENTAL PROTECTION AGENCY
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16. ABSTRACT

The Regional Air Pollution Study (RAPS), which encompasses the St. Louis Air Quality Control Region, is the largest and most comprehensive attempt to date to obtain a quantitative understanding of urban air pollution. Its aim is to describe the complex relationships between emissions to the atmosphere, atmospheric dispersions and transformation processes, and ambient concentrations of pollutants. In addition, numerous corollary studies are planned under the RAPS "umbrella."

An accurate, detailed and comprehensive inventory of emission to the atmosphere constitutes a basic input to this understanding. The RAPS emission inventory was planned to provide far more detailed information than has been available anywhere in the past; its aim is to obtain hourly data for key pollutants based insofar as possible, on measured values. Thus, emission data should be available for a base period of a year, commensurate in detail and accuracy with data on ambient concentrations and micrometeorological information gathered by the Regional Air Monitoring Stations.

The ultimate value of the RAPS Study will, it is hoped, not be confined to the St. Louis area, but rather will provide a model for future studies of this type in other areas. For this reason the National Air Data Branch provided complete documentation of all efforts connected with the assembly of the regional emission inventory so that the techniques and methodology developed for this project will be applicable to future studies.

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REGIONAL AIR POLLUTION STUDY (RAPS)

EMISSION INVENTORY HANDBOOK

TASK ORDER NO. 37

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Railroad Methodology and Inventory

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Purpose and Content of Handbook

The Regional Air Pollution Study (RAPS), which encompasses the St. Louis Air Quality Control Region, is the largest and most comprehensive attempt to date to obtain a quantitative understanding of urban air pollution. Its aim is to describe the complex relationships between emissions to the atmosphere, atmospheric dispersions and transformation processes, and ambient concentrations of pollutants. In addition, numerous corollary studies are planned under the RAPS "umbrella" dealing with land use, transportation planning, health effects and others.

An accurate, detailed and comprehensive inventory of emission to the atmosphere constitutes a basic input to this understanding. The RAPS emission inventory was planned to provide far more detailed information than has been available anywhere in the past; its aim is to obtain hourly data for key pollutants based insofar as possible, on measured values. Thus, emission data should be available for a base period of a year, commensurate in detail and accuracy with data on ambient concentrations and micrometeorological information gathered by the Regional Air Monitoring Stations (RAMS).

The ultimate value of the RAPS Study will, it is hoped, not be confined to the St. Louis area, but rather will provide a model for future studies of this type in other areas. For this reason the National Air Data Branch decided to provide complete documentation of all efforts connected with the assembly of the regional emission inventory in the hope that the techniques and methodology developed for this project will be applicable to future studies. The RAPS Emission Inventory Handbook is the result of this effort.

National Air Data Branch
MDAD, OAQPS, EPA

An Over View of the Regional Air Pollutions Study

The initial planning document for RAPS was a prospectus prepared by Stanford Research Institute for EPA-NERC (1). It consisted of four volumes: Part I - Summary, Part II - Research Plan, Part III - Research Facility and Part IV - Management Plan.

Based on the Prospectus, EAP developed a study plan(2).While following the general outlines of the Prospectus, it departed from it in many details.

An Experimental Design Plan, which integrated the various elements of RAPS and developed a time table for the project, was prepared by Rockwell International - Science Center (3).

These three documents as well as a Budget Summary (4), are contained in this section.

1. Regional Air Pollution Study: A Prospectus, Stanford Research Institute, Contract No. 68-02-0207, 1972
2. RAPS Series I Study Plan, October 1972
3. RAPS Experimental Design Plan, February 1974
4. Budget Summary: Prepared for this handbook by EAP-NERC April 1975

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REGIONAL AIR POLLUTION STUDY: A PROSPECTUS

Part I — Summary

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SRI Project 1365

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DON R. SCHEUCH, *Vice President,*
Office of Research Operations

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FOREWORD

This Prospectus was prepared by Stanford Research Institute for the Environmental Protection Agency under Contract No. 68-02-0207. While this Prospectus has been reviewed by the Environmental Protection Agency and approved for publication, approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor is it intended to describe the Agency's program.

The complete Prospectus for the Regional Air Pollution Study is presented in four parts.

Part I	Summary
Part II	Research Plan
Part III	Research Facility
Part IV	Management Plan

A table of contents for all parts is provided in each of the four parts to facilitate the use of the Prospectus.

ACKNOWLEDGMENT

This Prospectus was prepared at the Institute by a project team representing the full range of disciplines necessary for the comprehensive analysis of problems of air pollution. Research team members were drawn from four of the eight Institute Research Divisions, including the following:

Electronic and Radio Sciences
Physical Sciences
Information Science and Engineering
Engineering Systems

Because of the interdisciplinary nature of the effort, the contributions and research findings of many team members are distributed throughout this Prospectus rather than concentrated in one or more specific chapters. Accordingly, contributions are acknowledged below by general areas associated with the study of air pollution problems.

This Prospectus was prepared under the supervision of R.T.H. Collis, Project Director. The Project Leader was Elmer Robinson (now of Washington State University) until 15 January, when Richard B. Bothun, who had been Deputy Project Leader, succeeded him.

The main contributions were as follows:

- Elmer Robinson--Project leadership and the formulation of the Research Plan

- Richard B. Bothun--Project leadership and administrative management and the formulation of the Management Plan.

Technically, the principal contributions were:

- Richard B. Bothun--Management, scheduling, costing, planning

- Leonard A. Cavanagh--Air quality instruments, atmospheric chemistry

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- Ronald T. H. Collis--Meteorology, remote sensing, research planning

- Walter F. Dabberdt--Transport and diffusion modeling, meteorology, instrumentation

- Paul A. Davis--Solar radiation, tracer studies

- Roy M. Endlich--Meteorological models, satellite systems

- James L. Mackin--Helicopter and aircraft systems

- Elmer Robinson--Meteorology, instrumentation, atmospheric chemistry, research planning

- Sylvin Rubin--Data processing systems

- Konrad T. Semrau--Source inventory and emissions

- Elmer B. Shapiro--Communication systems

- James H. Smith--Atmospheric chemical transformation processes

- Eldon J. Wiegman--Synoptic climatology

Valuable contributions were made in the latter stages of the project by Dr. W. A. Perkins and Mr. J. S. Sandberg, consultants.

The Institute wishes to express its appreciation for the assistance and provision of information by many staff members of the Environmental Protection Agency, especially Charles R. Hosler, Contracting Officer's Technical Representative; Dr. Warren B. Johnson, Jr., Chief, Model Development Branch; Robert A. McCormick, Director, Division of Meteorology; and Dr. A. P. Altshuller, Director, Division of Chemistry and Physics.

Additionally, the constructive criticism and comment provided by members of the Meteorology Advisory Committee of the Environmental Protection Agency during the preparation of the Prospectus were of significant value, and our indebtedness is hereby acknowledged.

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I THE BASIC PREMISE

Both implicitly and explicitly, the Air Quality Act as Amended (1970) accepts the premise that air quality improvement can be planned scientifically. Specifically, it presupposes that emission standards can be set by reference to the desired ambient air quality standards, taking into account the manner in which the combined products of various sources in any particular area are dispersed or concentrated by physical, chemical, or meteorological processes. Following its announced policy of emphasis on enforcement, the Environmental Protection Agency is aiding state and local agencies to develop strategies to ensure compliance with such air quality standards as have been set. EPA is also following a policy to extend control procedures to achieve improved air quality standards as they are specified.

This overall concept will fail or succeed to the extent that the basic premise is true. Can air quality improvement be planned scientifically, at least to a useful degree, with existing knowledge and capabilities? If not, what is lacking? By what time can any shortcomings be rectified? The procedures, such as developing Implementation Plans called for under the Air Quality Act (or of filing Environmental Impact Statements under the National Environmental Policy Act), take for granted that existing knowledge and capability are at least minimally adequate for planning. Those who challenge this belief feel that all that can usefully be done at the present time and in the near future is to reduce all emissions to the minimum possible within the state of the art, regardless of any postulated requirements to meet what they may consider to be artificial air quality standards.

In either case, it is clear that room exists for considerable improvement in the knowledge and capability that are necessary for confidently relating cause and effect both between emissions and air quality and between control strategies and air quality.

There also can be no doubt as to the value of such a capability. Without such a basis, intelligent direction cannot be given to improving the state of the art of emission control; nor can correct decisions be made between alternatives in control strategies that do not depend on emission suppression and in allocating priorities and assessing cost-effectiveness in either case.

II SCIENTIFIC AIR QUALITY MANAGEMENT

The Basic Tool--The Mathematical Model

The central element of the concept of scientific air quality management is the mathematical simulation model. With this tool, the result of certain actions or inaction can be predicted. If the models are accurate and the data input correctly known or forecast, their output will show the effects of change, whether it occurs without specific intervention or as the result of such intervention. The accuracy of the models will depend on the degree to which the processes used are understood and can be described within the constraints of the mathematical technique. Accuracy will also reflect the inherent uncertainties of the statistical approach. In addition, since the atmosphere is the medium in which pollutants are dispersed, the only too well known difficulties in describing and predicting meteorological conditions must be recognized.

The Processes to be Modeled

However, before a simulation model can be formulated, it is necessary that the physical, chemical, and meteorological processes that are entailed be understood. In the very simplest form, models will consider only the gross relationships between emissions and air quality and will be correspondingly imprecise. More detailed and comprehensive models can be developed for certain processes, but they may be limited in their application by difficulties in providing adequate input data. The latter, particularly in regard to emissions, are often difficult to obtain at any price, and certainly their collection poses critical questions as to costs. Such factors become pertinent when the usefulness or value of any given model is considered. Will more timely and voluminous input data improve the accuracy of the models' output? Will more highly developed formulations of complex physical, chemical or meteorological processes more accurately describe and predict what is happening in the real world? How accurate are such descriptions and predictions anyway? These questions must be faced and satisfactorily answered if the models are really to play a key role in air quality management.

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Accuracy

A most important question is the accuracy of the models. If control strategies with far-reaching economic and social effects are to be imposed on the basis of a simulation model it is more than desirable that the model's output be accurate and sufficiently precise to enable the effects of the strategies to be evaluated. In dealing with control and abatement procedures that require large increases of investment in plant or of costs of operation, especially where the relationship between such procedures and the hoped for improvement in air quality is not linearly related, it is not enough to know that the model is accurate in general terms. It must be capable of providing more precise information on the benefits in air quality to be derived from the costs of the control and abatement procedures proposed. Without such a capability, the procedures could be very uneconomical and absorb effort and resources that could be used more profitably elsewhere. These aspects become increasingly important as the more obvious control and abatement procedures are adopted and attention is turned to the more marginally productive strategies.

Above all, in the use of modeling techniques in air quality management, the need is most urgent to ensure that all concerned have confidence in the approach. With large financial involvements, with the livelihood of whole communities at stake, with the tremendous pressures on limited resources to plan, implement, and enforce control strategies, it is imperative that decisions are not only wisely taken but also that they are readily seen and recognized as being wisely taken. Sound modeling capability serves all aspects of this obligation and provides the evidence on which sound enforcement strategies can be sustained.

Current Limitations of Modeling

As noted above, the position regarding air quality modeling at the present time is far from satisfactory. A wide diversity of such models exists or is being developed, and these models cover a range from quite limited problems--such as diffusion from a single point source--to the extended scale covering large urban complexes. Only in a few cases that are concerned with fairly simple problems are the models well tried and sufficiently verified to warrant confidence in their use.

There are many reasons for this state of affairs. The major reason, quite simply, is that solving the problem has just not been undertaken on an adequate scale. Progress made with the limited funds and resources available to date has lagged far behind the need, which itself has been recognized as urgent only in the last year or so. As indicated, the development and verification of suitable models are very difficult, especially on a major scale, and depend strongly on the availability of adequate data on which to base the formulation and to develop its application. It is possibly even more difficult to assess its capability and measure its precision accurately, especially where long time periods are needed to provide an adequate basis of comparison.

Steps to Improve Models

The steps taken in conceiving, developing, and proving an air quality model are shown diagramatically in Figure 1. To the present, most progress has been made in understanding the processes and in formulating the model, even though the item in the diagram--"Observations of Various Conditions"--has been limited if not thoroughly inadequate. For the latter reasons, operation of the model both for description and prediction has generally been constrained, and the comparison and evaluation of its results against observations have frequently been inconclusive or inadequate, if indeed they have been attempted at all.

The decisive limitation in the whole process lies in the first area noted in the diagram--"Observation of Various Conditions." This area is fundamental to all aspects of the problem, and its shortcomings cripple every subsequent endeavor. Thus, many existing models are based on the very limited data that have been acquired routinely for quite different purposes, e.g., airway weather forecasts, and are woefully inadequate in both extent and spatial and temporal resolution for the development and verification of models or even, in some cases, for developing an adequate understanding of the processes involved.

The limitation of basic data results from the fact that the collection of such data on a sufficiently continuous scale in space and time and over a large enough area for long enough periods is extremely costly, even if suitable sensing devices exist. (The situation is much worse when there is no practical or reasonably economical way to make even the individual observations--as is the case with certain pollutants.) Even when attempts have been made in certain circumstances to set up special networks of observational facilities and carry out intensive data collection programs, the results have often left much to be desired and reflect the shortcuts that have been taken because of cost in instrumentation and in collecting and handling the data. Particularly in the past, when much reliance had to be placed on manual procedures of data collection and analysis, the data acquired under such programs were limited and somewhat piecemeal--serving

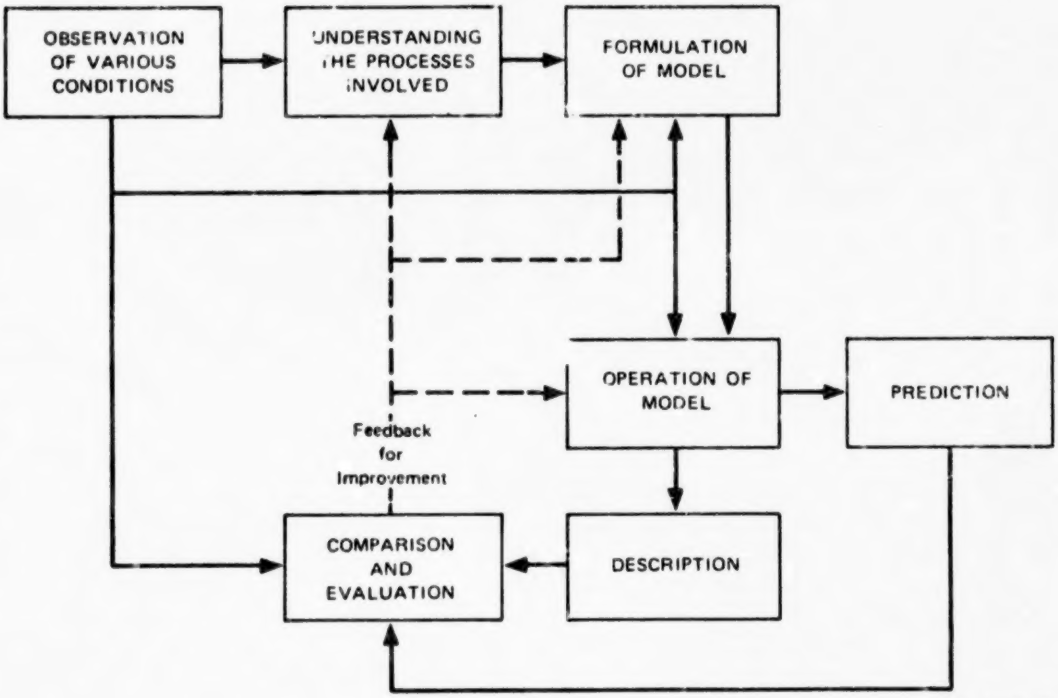
OBSERVATION OF VARIOUS CONDITIONS
UNDERSTANDING THE PROCESSES INVOLVED
FORMULATION OF MODEL
OPERATION OF MODEL
PREDICTION
Feedback for Improvement
COMPARISON AND EVALUATION
DESCRIPTION
SA-1365-49

FIGURE 1 STEPS IN THE AIR QUALITY MODEL

only the immediate purpose for which they were collected--and remaining of little value for use in other investigations.

Even with the emergence of relatively moderately priced automatic data processing facilities, the acquisition of basic data remains a considerable and costly undertaking, especially on a major and extended scale. But to those considering the major and pressing problems of air quality management, it has become increasingly clear that little progress can be made in the solution of such problems unless they are treated on a major and extended scale. Only by fully recognizing the magnitude of the technical problems in the way in which current legislation and EPA policies have recognized the whole question of air quality, can adequate tools be developed for scientific air quality management.

The Regional Scale

The difficulties of air quality management are apparent in the context of Air Quality Regions, where emission standards within the region are to be related to air quality standards. For these purposes it is necessary that at all scales, from the local to the extended regional scale, there is an adequate understanding of how emission from the several sources combine and react to produce concentrations of specific pollutants throughout the area. This is particularly the case where the air quality of large rural and suburban areas is greatly affected by emissions from remote urban centers that may be up to 100 miles away. Control and abatement procedures must take these indirect effects into account. To formulate economical and realistic strategies for such procedures, however, it is necessary also to consider the less direct aspects of health, economics, land use, and community planning in the urban/rural complex.

III THE REGIONAL AIR POLLUTION STUDY (RAPS)

Concept

The problem of effectively managing air quality within the framework of current legislation on a regional basis is thus seen to be extensive and complex. The need to evaluate and improve control strategies already adopted or to identify new approaches must be considered on this basis. Realization of this, together with the recognition that much of the existing understanding is based on limited and piecemeal data, has led to the concept that it is necessary to make a new large scale integrated attack on the total problem. By effectively coordinating efforts on a number of interrelated problems, a combination of resources can be brought to bear in an economical and productive manner. This concept is particularly applicable to the problems of air quality management on the regional scale, where it is necessary to relate the effects of the urban center on the suburban and rural environs.

Only within such a framework can the necessary basic data on emission sources, meteorological factors, and other physical and chemical effects be studied in appropriate relationships and used to improve the basic understanding and formulation of the appropriate air quality models. Only on such a basis can the results of such models be evaluated by comparison with adequate data on the true nature of conditions. Only with such a background of relevant data can the ramifications of air pollution in the urban/rural complex be adequately understood in terms of health, economics, land use, and community planning so that control strategies can be formulated and ordered with maximum effect.

It is the purpose of this Prospectus to identify the separate elements constituting such an undertaking and to describe how it can be carried out.

In this Part I--General Summary--the major concept of RAPS is presented, with an outline description of the Research Plan, the Facility, and the Management Plan (which includes budgetary information). Subsequent sections, following the same pattern, provide fully detailed descriptions. Where appropriate, the rationale for the approach proposed is discussed.

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Purpose

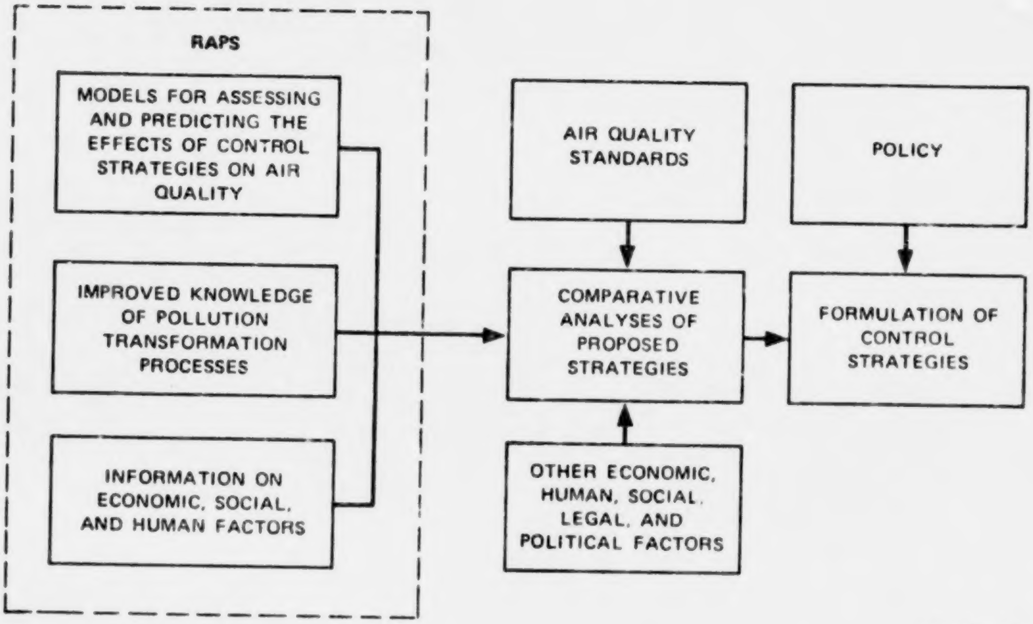
The initial purpose of the Regional Air Pollution Study is to evaluate and demonstrate how well the effectiveness of air pollution control strategies on all scales appropriate to air quality within a region can be assessed and predicted. Its further purpose is to serve as the basis for developing improved control strategies that can be applied generally.

Both purposes require the development of a better understanding of the chemical, physical, and biological processes that are entailed in determining the concentration of pollutants and the modification of air quality. They also require a better understanding of certain human, social, and economic factors that are significant in formulating control strategies. Above all, however, they require the testing, verification, evaluation, and improvement of mathematical simulation models that are the basic tools of scientific air quality management and a knowledge of how such models can be used the most effectively.

It should be noted that the overall purpose of RAPS is to provide the basis necessary for the formulation of control strategies rather than to develop control and abatement procedures as such. Its relationship to the analytical and decision-making processes in formulating control strategies is illustrated diagramatically in Figure 2.

Organization

Since the organiztion of the RAPS program by design is an integration and combination of endeavors, it cannot be described briefly. However, its essential structure follows from the purposes noted. Within this structure, key tasks with well defined objectives and a series of sub-tasks that are often interrelated and interdependent can be identified. Some of the activities constituting these tasks are in fact part of ongoing programs within the existing research organization of EPA. Following basic management principles, it is proposed that the work of the overall study be identified and organized as separate tasks, for each of which the objectives are specified, the purposes described, and the responsibility clearly defined. These taks will be arranged in a series of levels that will reflect the dependence of one activity on another and will establish the chain of responsibility of the task leaders. This responsibility is functional rather than administrative and relates to the technical accomplishment of the research task.


RAPS
MODELS FOR ASSESSING AND PREDICTING THE EFFECTS OF CONTROL STRATEGIES ON AIR QUALITY
IMPROVED KNOWLEDGE OF POLLUTION TRANSFORMATION PROCESSES
INFORMATION ON ECONOMIC, SOCIAL, AND HUMAN FACTORS
AIR QUALITY STANDARDS
COMPARATIVE ANALYSES OF PROPOSED STRATEGIES
OTHER ECONOMIC, HUMAN, SOCIAL, LEGAL, AND POLITICAL FACTORS
POLICY
FORMULATION OF CONTROL STRATEGIES

SA-1365-50

FIGURE 2 RAPS ROLE IN THE OVERALL EPA FUNCTION OF FORMULATING CONTROL STRATEGIES

The material to be used in these research tasks will be provided by the facilities and support elements of RAPS, some of which will have a general role to play only, while others will be substantially engaged in specific research tasks. Again, EPA groups outside the RAPS organization will provide some support and facilities.

The various facility and support elements will be the responsibility of designated leaders, but here the responsibility is administrative as well as functional. Thus, the manager, say, of a data acquisition network will be responsible administratively for the performance of the personnel and equipment assigned for this purpose and for the quality of the product of the network. Functionally, his responsibility is to provide data as required for the various research tasks, of one or more of which he may be the leader. The general scheme is indicated in Figure 3.

The organization of the research tasks and the functional roles of the support and facilities elements are set out in the Research Plan. The organization and the administrative structure of the support and facilities elements are set out in the Management Plan. In both cases, only the roles and responsibilities of the participants in relation to RAPS are considered. Thus, the contribution of other EPA research programs to the RAPS must be identified in terms of specific functional contributions as described in the research tasks.

The costs of such participation by personnel of other EPA research programs, as would also be the case with facilities and support provided from outside the RAPS organization, are included in the RAPS budget for the purposes of this Prospectus (interdepartmental adjustments can readily be effected by transfer procedures as necessary).

The general data base acquired under RAPS and, subject to availability after meeting primary responsibilities, the resources and facilities of RAPS will be available to other research programs of EPA, or for that matter, to other agencies. Any additional costs incurred would naturally be a charge on such other programs and budgeted accordingly.

By design, this Prospectus is based on the principle that RAPS should be an independent, self-sufficient activity of EPA, certainly for planning purposes. The possibility that other research programs and operational activities could make valuable contributions has been considered, especially in the selection of the site. In the data collection and observational programs, however, such contributions have been considered as supplementary rather than complementary, otherwise the tasks of specifying facilities and assessing costs could not have been accomplished at this time.

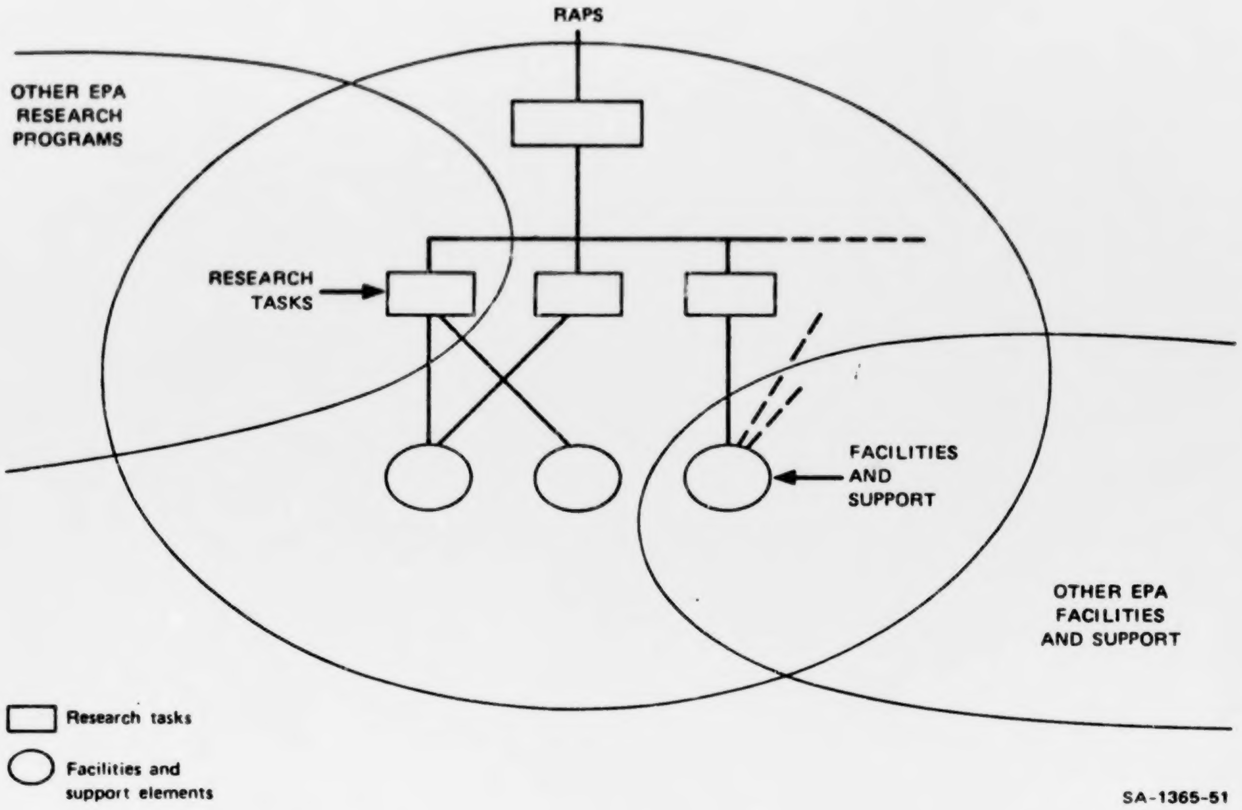

RAPS
OTHER EPA RESEARCH PROGRAMS
RESEARCH TASKS
FACILITIES AND SUPPORT
OTHER EPA FACILITIES AND SUPPORT
Research tasks
Facilities and support elements
SA-1365-51

FIGURE 3 GENERAL SCHEME OF THE RAPS RESEARCH TASKS

In any case, although some economies and improvements might result from integrating the resources and research efforts within RAPS and with those of other programs planned for the St. Louis area, it is considered that the scope and importance of the RAPS program require that it be carried out as a principal endeavor. Any proposals to share resources with other programs should be carefully evaluated to ensure that efforts are not deflected from the main goals of RAPS.

In this context, it should be stressed that in the other programs noted the emphasis is primarily on the scientific aspects of the problems attacked or on operational problems quite different from those of RAPS. RAPS is concerned with the development of improved air pollution control strategies--and this concept must dominate all its research tasks.

Objectives

The overall objectives of the RAPS are to:

(1) Demonstrate and evaluate how well the effectiveness of air pollution control strategies may be assessed and predicted within an air quality region.

(2) Provide a basis for developing improved control strategies.

The specific objectives of the four principal tasks under which the overall objectives will be accomplished are described below. Each principal task is divided further into a structure of subordinate tasks as discussed later in Section V in which are presented the objectives of each subordinate task, together with details of the problems to be solved, the approach to be followed, the schedule, budget, and interrelation to other tasks.

The objectives of the four principal tasks are to:

- Test, verify, and evaluate the capability of mathematical simulation models to describe and predict the transport, diffusion, and concentration of both inert and reactive pollutants over a regional area. (100 series*)

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* These refer to a numerical classification system of tasks within the Research Plan.

- Develop an improved understanding of the chemical, physical, and biological processes that are entailed in determining the concentration (the dispersal) of polltants and the modification of air quality. (200 series)

- Develop a better understanding of factors of significance to the design of improved control strategies in the urban/rural complex, including health and economic effects and the role of land use and community planning. (300 series)

- Develop improved technology that can be applied in local and regional control agency operations, including techniques for emission inventories, air quality and meteorological measurement, data handling and analysis, and the objective assessment of effectiveness. (400 series)

IV SITE SELECTION

The best site for the RAPS program is centered in St. Louis, Missouri. This selection was based on the need to find a large city lying within the central United States, which was away from oceans and mountains and which typified the coal-burning industrial nature of many urban areas yet which lay in an extended region of suburban or rural country. Some 33 Standard Metropolitan Statistical Areas (SMSAs) larger than 400,000 population were considered in terms of the following criteria:

- Surrounding area--This criterion includes measures of the isolation of the SMSA from other SMSAs to gauge interarea pollutant tendencies, measures of the rural fringe to be anticipated, and similar location factors. Clear-cut relationships and interactive mechanisms between the urban and rural areas are essential. The absence of a surrounding area with a low level of development, e.g., agricultural, eliminated an area from further consideration, as did the proximity of large bodies of water.

- Heterogeneous emissions--Several tests were applied for this criterion, including fuel used, types of industry in the region, and the current pollution mix. An important specific factor was the extent of coal usage because of its relation to both sulfur oxides and particle emissions. A lack of sulfur oxide emissions eliminated an area.

- Area size--This criterion gave a general measure of the expected scope and magnitude of the Regional Study for each candidate site.

- Pollution control program--The various candidate areas had considerable variation in their existing control programs. It appeared desirable that the Regional Study be carried out at a site where the control program is generally well developed. Such a site would provide a background of data and general experience that could be used to establish the Regional Study. In addition, a Central District program could provide initial contacts with industrial sources for the gathering of source inventory data.

- Historical information--Historical data, including meteorological and pollution, applicable to a site also varied widely. In

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general, a site tended to be more attractive as the quantity of historical data increases. Care was exercised to distinguish between quantity and quality.

- Climate--The site should possess a climatic representative of a large section of the nation or other potential sites. Moreover the climate should permit experimental work throughout the greatest possible portion of the year.

The comparison of the characteristics of the 33 candidate areas with these criteria reduced the group to four most appropriate possible areas. These are Birmingham, Cincinnati, Pittsburgh, and St. Louis.

A final review of the respective merits of the four candiate sites led to the following comparative assessment

Criterion	Birmingham	Cincinnati	Pittsburgh	St. Louis
Surrounding area	Fair	Poor	Good	Good
Heterogeneous emissions	Fair	Fair	Fair	Good
Area size	Good	Good	Good	Good
Pollution control program	Poor	Good	Good	Good
Historical information	Poor	Good	Fair	Good
Climate	Good	Fair	Fair	Good

On this basis, St. Louis emerged as the obvious prime choice.

V THE RESEARCH PLAN

Introduction

The Research Plan and its rationale are outlined in broad terms, followed by a detailed specification of the task structure that will be set up to accomplish the objectives of the plan.

The scope of research efforts in the field of boundary layer simulation modeling centers in the need to understand, describe, predict, and ultimately control air quality in the lowermost stratum of the atmosphere. Simulation modeling provides the necessary link between inferences gleaned from air quality data obtained at isolated, single-point monitoring stations and the broad, yet detailed, picture of air quality that is required over an entire urban region; it also permits assessment of the ramifications of actual or projected growth (zoning) patterns and emission control (proportional versus selective) prodecures.

Simulation modeling of the boundary layer refers precisely to physical or mathematical modeling of the atmospheric planetary boundary layer--the lowermost stratum of the atmosphere (on the order of 1 km in depth) in which the effect of surface friction on the wind field is manifested. From a more practical standpoint, it is also the layer in which atmospheric pollutants are generally emitted, transported, diffused, and transformed. Mathematical models include, generally, gradient-transfer, similarity, Gaussian plume and puff, and statistical formulations, while physical modeling is done with the aid of wind or water tunnels. The utility of the mathematical models lies in their ability to describe and parameterize the physics of the problem over a large region and to predict meteorological and air quality changes that may occur either in time (as a result of the progression or development of weather systems) or from the alteration of emission patterns. Ideally, mathematical models are capable of achieving arbitrary degrees of temporal and spatial resolution to solve specific problems. High resolution, for example, may be necessary when considering pollutant concentration in urban core areas, whereas relatively low spatial resolution may be required for the study on the mesoclimatic scale. Physical models perhaps are less flexible yet are ideal for evaluating the gross features of, for example, pollutant distributions in extremely homogeneous or complex locations.

It is highly desirable that the RAPS program evaluate the ability of the more promising models to simulate the atmospheric environment on both the micro- and mesoscales. In this regard, the models should be evaluated according to the specific function that they may serve. Specifically, evaluation programs are recommended for the following three functional model types: (1) diagnostic, (2) predictive, and (3) climatic. The primary emphasis at this time should be placed on the diagnostic model types, because the current or steady-state distribution of pollutants on the mesoscale must be described before detailed prognostic models can be developed. Prognostic or predictive models in this sense do not include diagnostic models, which may be input with anticipated meteorological and emissions data to simulate an expected condition. Rather, predictive models use current initial conditions to predict (on the order, say, of one or two days) meteorological and perhaps emission fields, thereby predicting the level of air quality for some time in the future. Moreover, emphasis must be given to the development and evaluation of dynamic climatological models that have the ability to describe the mesoclimate and changes that may result from mesoscale urbanization.

Toward achievement of these goals, it is essential that the various models be evaluated (and refined as appropriate) with "real" data collected in the field. Such data collection will further one's ability to understand and simulate the lower atmosphere on the mesoscale (on the order of 250 km). But unless one is able to observe the process he is attempting to describe, simulation modeling may be little more than an esoteric exercise. A vast amount of effort has been expended in the development of the various mathematical models and in their subsequent evaluation. In almost no case have the observed data been obtained on a scale compatible with the resolution of the model computation. Virtually all meteorological and air quality data collected on a routine basis for purposes other than model verification are the result of single point measurements (or, at the very best, several adjacent points). As such, the observation is a representation of very localized conditions and, in perspective, is a measure of the integrated effect of various scales of motion: micro, meso, and macro. In many cases, it is the microscale phenomena that predominate and there can be little surprise at the inability of numerical models to simulate the observation when the model, in fact, may predict only average conditions over a broad area, say a one kilometer square or larger. Therefore, another objective of the program should be the definition of the spatial variability of ambient air quality, as well as the spatial resolution of the simulation models. In practice, a feedback between observations and computations should result whereby the observations define the appropriate time and space scales that the models need to achieve, and eventually the models are used to describe spatial and temporal variations on the basis of a few representative measurements.

Federal air quality guidelines define levels of air quality on several time scales: hourly, eight-hourly, daily, and annual. On the basis of results from the observation/modeling programs, spatial criteria also may need to be established. It appears equally necessary to define criteria where the air quality is evaluated in parallel over various lengths (or areas or volumes) and time scales. In this regard and in consideration of the requirements of model verification, the data collection program must also concern itself with the potential of remote (long-path) observation techniques where a particular contaminant can be measured on the appropriate spatial scale.

In summary, an extensive air monitoring network is required to define the scope of the problem and to evaluate and refine the mathematical models that are to simulate the level of air quality over a broad region. As such, the network should be not only extensive but also flexible so that it will serve the many purposes of the simulation program. It must be capable of providing data from the substreet microscale to the regional mesoscale. The observations will also be used to evaluate these models on a variety of temporal scales: simulation of existing conditions (diagnostic requirement), prediction of short term changes (prognostic requirement), and evaluation of potential mesoclimatic alterations (extended prognosis). (Physical modeling techniques could be used to supplement the field observation program in urban core areas where the complexities of building structures may severely limit routine in-situ measurements on a practical basis, but this approach is more appropriate for studying specific and linked problems).

Model Evaluation and Verification Program (100 Series)

The various simulation models can be evaluated most efficiently by considering the models in terms of the functions that they may be expected to serve. For convenience, these functions may be divided into three parallel types: (1) the time frame and resolution of the model, (2) the spatial frame and resolution, and (3) the class of contaminants to be considered. Therefore, the models may be classified according to whether they simulate the quality of the air in terms of the concentration distribution of inert, reactive, or particulate contaminants over either localized or expansive regions for current or forecasted conditions. Accordingly, there are about a dozen functions that a model or models may be expected to fulfill; that is, there may be localized, diagnostic models for inert pollutants that have application in planning and evaluation studies or regional, prognostic models of reactive contaminants required for emissions control procedures. Figure 4 illustrates this concept, as well as the subsequent steps in a model evaluation and verification program.

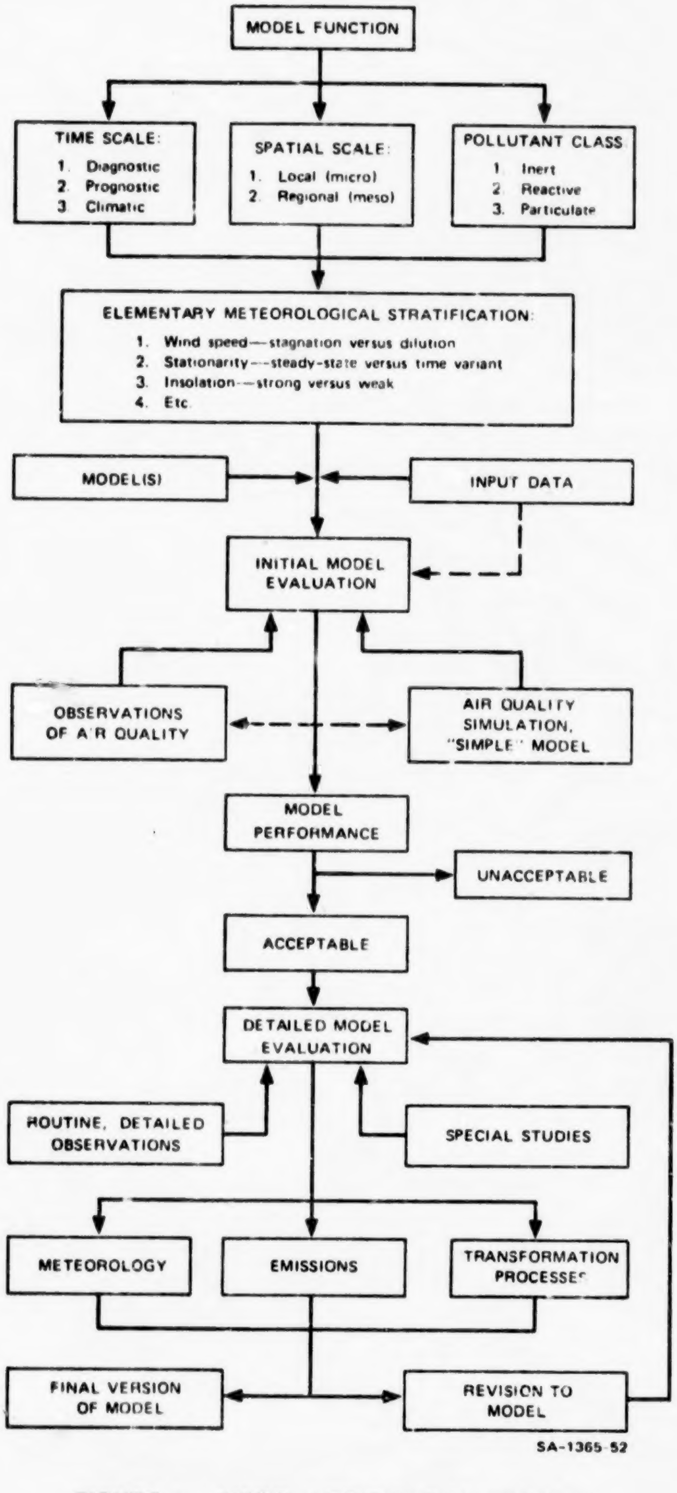
MODEL FUNCTION
TIME SCALE:
1. Diagnostic
2. Prognostic
3. Climatic
SPATIAL SCALE:
1. Local (micro)
2. Regional (meso)
POLLUTANT CLASS:
1. Inert
2. Reactive
3. Particulate
ELEMENTARY METEOROLOGICAL STRATIFICATION:
1. Wind speed—stagnation versus dilution
2. Stationarity—steady-state versus time variant
3. Insolation—strong versus weak
4. Etc.
MODEL(S)
INPUT DATA
INITIAL MODEL EVALUATION
OBSERVATIONS OF AIR QUALITY
AIR QUALITY SIMULATION, "SIMPLE" MODEL
MODEL PERFORMANCE
UNACCEPTABLE
ACCEPTABLE
DETAILED MODEL EVALUATION
ROUTINE, DETAILED OBSERVATIONS
SPECIAL STUDIES
METEOROLOGY
EMISSIONS
TRANSFORMATION PROCESSES
FINAL VERSION OF MODEL
REVISION TO MODEL
SA-1365-52

FIGURE 4 MODEL VERIFICATION PROGRAM

It may be further desirable to test the various models under a variety of distinct meteorological conditions. One such stratification could be the separation of low and moderate-to-high wind speed cases (isolation of stagnation conditions); other distinctions may be made between near steady-state and strong advective conditions or strong versus weak insolation.

At this point, the purpose of the simulation will have been defined and certain forcing physical criteria established; specific models falling within this framework can then be introduced for evaluation and subsequent verification. It is strongly recommended that the performance of the models initially be evaluated against both observed measures of air quality and the predictions of a simple standard (or reference model or models). The simple model used by Hanna (1971)* or a relatively simple box or Gaussian formulation (see Chapter III in Part II) should be considered. Quantitative, statistical techniques then should be applied to test the model against the reference and the observations. If the test model cannot show significant superiority to the reference, it can be safely excluded from the later, detailed evaluation program. Emphasis should also be placed on a qualitative assessment of the extent and nature of the required input data. If a given model performs well but requires input data that may not be readily available at the present or in the foreseeable future, then alternative formulations or parameterization may be necessary for further consideration.

Having initially demonstrated its feasibility, the model should be evaluated in detail to define both its strong and weak points so that refinements may be made. This detailed model evaluation program should include both fundamental and applied research tasks for the testing of the basic components of the model, namely, metorological, emissions, and transformation processes. The applied tasks are, in effect, individual evaluation programs for the three process areas (or submodels). Submodel predictions of wind, turbulence, stability, emissions, plume rise, reaction rates, and so forth would be compared with routine observations from the research network (which may not be strictly routine for nonresearch programs). The sensitivity of each model and submodel should be evaluated with regard to the response of the output (model prediction) to variations of the input parameters. In addition to these direct or applied tasks, there is an acknowledged need for complementary research programs of a more fundamental nature. These would be directed toward providing a better understanding of the physical nature of the various physical processes so that the models may be revised accordingly and in conjunction with the requirements resulting from the applied program. Many of these fundamental programs can be anticipated; however, others, will result only as output requirements of the initial, detailed evaluations. The fundamental programs or special studies are given in detail in Part II.

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* See Hanna, S. R., "Simple Methods of Calculating Dispersion from Urban Area Sources," paper presented at the Conference on Air Polluation Meteorology, Raleigh, N.C., Sponsored by Amer. Met. Soc., April 1971.

Meteorological Factors

The transport and diffusion of pollutants in the atmospheric boundary layer is a basic aspect. The RAPS program will include a comprehensive network of observing stations at the surface, throughout the regional area, that will provide the data from which trajectories and stream line flow patterns can be calculated and used to determine the transport of pollutants. Practical models usually will be based on less sophisticated wind transport data, and thus the availability of this detailed information will permit a candidate meteorological submodel to be evaluated independently and, if necessary, modified and retested.

Since total atmospheric transport of air pollutants is not always adequately depicted by surface meteorological measurements, it will be necessary to define the important transport weather parameters above the surface to altitudes between 1000 m and 1500 m. The RAPS program proposes to do this by extensive use of instrumented aircraft with supplemental use of balloon sounding systems.

Regionwide measurements are not totally adequate to interpret the meteorological conditions within the meteorological boundary layer and several specific research studies are incorporated in the RAPS program to define in more detail a number of important boundary layer transport processes. It is generally recognized that mixing and transport conditions depend strongly on the nature of the underlying surface and that built-up urban areas and relatively smooth rural and agricultural areas can affect an air mass differently as it moves across these areas of different roughness. To a certain degree, these effects can be predicted, but how to account for changing conditions within an air mass as it moves from one roughness regime to another is relatively unknown.

Specific experiments using specially dispersed tracer materials, constant-altitude balloons, and special aircraft instrumentation will be carried out to develop techniques for including changes in surface roughness in the meteorological boundary layer submodel. Within an urban area, building temperature, as well as the changes in building height and density, affect the meteorological transport processes, and thus special care will be given to experiments that will greatly improve understanding of the interactions between urban surface characteristics and the pollutant transport processes.

The RAPS program will also include studies of meteorological dispersion of effluents from specific single sources to characterize the interactions between these effluents and environmental factors. One very significant study topic is that entailing the dispersion of pollutants from tall stacks across very rough areas characteristic of an urban area. From this type of study, a better understanding can be obtained of pollutant transport in an urban area and this information can be used as a "feedback loop" in the evaluation and further development of diffusion models.

Pollutant Source Estimates

Pollutant emissions from both moving and stationary sources are an obvious ingredient of any air pollution situation. The RAPS program must have as an integral part a detailed, ongoing air pollutant inventory program. This program must include, in addition to data on source emission rates, the development of techniques by which these emission rates can be estimated for specific periods of time. These time periods may be as specific as a given hour for a particular day and will be necessary to support the short time simulation modeling efforts. Thus the emission estimation submodel will have two major components: the inventory of source emissions and the development of techniques by which this inventory can be used to estimate emissions over specific time periods.

It is expected that the RAPS emission estimation techniques, including the programs for inventorying, data handling, and data storage, will also have wide applicability to regional air pollution control programs because of the general importance of emission assessment in a control operation. Thus the techniques for emission assessment will be a significant and relatively early area of RAPS technology development that can be applied to the nation's air pollution control programs.

Air Quality Measurements

The acquisition of air quality data is another major RAPS activity. Air quality data are incorporated in model verification studies through the development of either average concentrations at a given set of points or average concentration patterns over a given test area. The RAPS program will include model verification studies of a variety of pollutants but especially for major pollutants for which quality criteria have been or will be published. These pollutants currently include SO_2, CO, NO/NO_2, photochemical oxidants, hydrocarbons, and suspended particles. Air quality criteria are expected to be published for lead aerosols and fluorides. There is also considerable air pollution control interest in mercury, H_2S, nonspecific odors, asbestos, toxic heavy metals, and polynuclear aromatic compounds. Over the five-year research period estimated for the RAPS program, it can be expected that the simulation model verification program will require regionwide data on ambient air concentrations for each of these materials. To meet these needs for air concentration data, the RAPS design provides for an extensive program of air quality monitoring, including a network of continuously operating telemetering stations.

Atmospheric, Chemical, and Biological Processes (200 Series)

In pollutant dispersion modeling studies, the transformation or loss of pollutants in the atmosphere after emission from the source and before arrival at the receptor point has been either ignored, i.e., pollutants are assumed to be stable, nonreactive compounds, or treated in a very simple manner, i.e., application of a simple "half-life" term. It is known from both theoretical and experimental studies that pollutant compounds in an ambient atmospheric environment are affected by a variety of complex reaction processes. These processes can rapidly reduce the concentrations observed in the atmosphere, i.e., precipitation will scrub contaminants out of the air at a rate dependent on precipitation characteristics and on the nature of the pollutant. There are also situations in which pollutants are formed in the atmosphere by reactions containing one or several other pollutant compounds. Notable in this category are the photochemical processes used in the formation of photochemical smog where both gases and aerosols are formed in the atmosphere by chemical reactions.

The RAPS program will carry out specific research studies to determine how pollutants are transformed or scavenged in the atmosphere with special reference to the major pollutants--SO_2, NO, NO_2, CO, hydrocarbons, and particulate materials. These transformation studies will include reactions with other atmospheric constituents and the formation of aerosols in the cases of SO_2, NO_2, and hydrocarbons. Photochemical reactions are involved with SO_2, NO, NO_2, and hydrocarbons. For CO, the scavenging mechanisms appear to be centered in the biosphere, although atmospheric chemical reactions may also occur.

A typical research study in this transformation task program will be the "mass balance" design in which the pollutant, e.g., SO_2, will be followed through the atmospheric reaction processes--SO_2 to H_2SO_4 or $(NH_3)_2SO_4$

to sulfate in rain--and the various reaction rates and other parameters determined. Surface reactions and vegetation pickup can also be important. The result will be a set of transformation submodels that provides a technique to predict the atmospheric transformation of the major pollutants.

Precipitation is generally considered to be a major process bringing about the removal of both gaseous and particulate material from the atmosphere. As such, it is a major scavenging process. However, this pollutant scavenging can also have a major effect on the chemical content of precipitation and through this on the regional environment. Recently "acid rain" in Sweden received wide publicity, and it is likely that important changes in precipitation chemistry as a result of air pollutant emissions also could occur in the United States. The RAPS program will include a significant study of precipitation chemistry and its relation to regional air pollution emissions, with the goal of obtaining quantitative measures of the interaction between precipitation processes and pollutant emissions.

Within an urban area that is adversely affected by air pollution, visible pollutants from sources and as a general urban haze cloud are probably a major public complaint. The particles that constitute this visible urban pollution can come from two pollutant sources--from the direct emission of solid and liquid particles such as dust, fly ash, fumes, or smoke and from the formation of particles in the atmosphere as a result of reactions among various gaseous pollutant emissions. Photochemical smog reactions in the atmosphere constitute one source of the haze that can afflict urban areas. Transformation of SO_2 into a sulfate aerosol is considered to be another common source of urban haze.

In the RAPS program, a major effort will be directed toward finding the reasons for the formation and dispersion of urban haze. The ultimate goal beyond the RAPS program would be the development of means by which the formation processes could be abated. While such an abatement goal could be expected to require the reduction of source emissions, until the formation process can be described, the specification of a source control program can be little more than educated guess work.

The RAPS aerosol study program will include extensive sampling of aerosol constituents and the characterization of size distribution. Detailed emission data will be available as will comprehensive information on atmospheric chemical composition. Translation of these observational results into a haze formation submodel will depend on relating these field data to laboratory and theoretical studies of aerosol formation and the development of rational hypotheses for urban haze formation. The solution of urban pollution haze problem is probably the most difficult of the several RAPS tasks. By contrast, it seems quite probable that the general public will consider it vital to find solutions to visible pollution and urban haze formation before success can be claimed for an urban air pollution control operation.

Human Social and Economic Factors (300 Series)

In the decision-making processes used in formulating air pollution control strategies, it is necessary to consider factors other than the basic cause and effect relationship between sources and air quality. Human, social, and economic factors are involved, either directly, as when they are manipulated to effect reduction of pollution, or indirectly, in terms of the costs and benefits of control strategies. To provide a better understanding of such factors, it is intended to take advantage of the unique facility provided by the RAPS organization to collect relevant data in an economical, well focussed manner.

Data would be acquired on both human and social factors (e.g., health, population distribution, land use, and labor force characteristics) and the economic aspects (i.e., the cost of air pollution and of control and abatement procedures).

Particularly in connection with the source inventory surveys, it is hoped to collect information (subject to legal and other constraints regarding privacy) that may contribute to a better assessment of the costs entailed in staffing and operating control and abatement devices or in the costs that result from modifications of the productivity of the plants in question.

This element of the research plan would relate to the specific conditions in a given study area and would be made available for studies directly related to this area. The material acquired and the lessons learned in collecting it also would be used to develop more generally applicable information and methodologies in Task Area 400 described below, which is concerned with the transfer of technology acquired in RAPS for use in wider contexts.

RAPS Technology Transfer (400 Series)

It clearly is desirable that the knowledge and technology developed in the RAPS program be made available for air pollution control purposes as early and as effectively as possible.

This requires passing on improvements and innovations in the techniques of measurement, data handling, and utilization in a direct form. It also entails conversion and distillation of the knowledge and technology developed in RAPS in the specific test region to a generalized form so that it can be applied in other regions and for other problems with minimum difficulty. Above all, this task provides the basis for the development of improved control strategies, by national, state, and local agencies.

The approach follows four main lines. The first approach is the development and description of techniques and criteria by which the basic air pollution factors can be assessed and monitored on an operational (as distinct from research) basis. Particular attention will be given to identifying and developing new techniques of monitoring atmospheric and air quality conditions on extended scales appropriate to regional and subregional control strategies so that the costs may be minimized. The use of aircraft and remote probing techniques either from such aircraft or from the surface are especially suited to this purpose, and every attempt should be made to advance their applicability.

The second approach is the provision of tested, effective simulation models suitable for other areas and conditions. The third approach is the development of a methodology for assessing the validity (in terms of confidence, accuracy, precision) of the preferred models for varying degrees of input data quality. The fourth approach is the provision of methodologies for determining and assessing other factors such as health effects and economic costs and benefits relevant to the formulation of improved control strategies.

First priority will be to consider current data resources, deficient though these may be, with emphasis on the optimum methods of providing more complete data for input to models and for air quality monitoring and model verification purposes. The needs of the states and local authorities (and EPA) to improve and extend Implementation Plans will be treated first, with concurrent though subordinate attention to environmental impact statement requirements. The first milestone will be the advancement of interim capabilities for these purposes. Thereafter, a more complete and detailed facility will be developed, covering all aspects of control strategies formulation then current and capable of extension to other pollutants and so forth as the need arises.

Schedules and Task Specifications for the Research Plan

Introduction

The following schedules and specifications show how the Research Plan would be accomplished within the proposed 5-year period. They follow a structure reflecting the principal objectives of the study. Thus, each principal objective is approached within principal tasks numbered 100, 200, 300, and 400, respectively. Separate research tasks are assigned numbers within the 100, 200, 300, and 400 series, and a further division into subtasks is provided by adding numbers after the decimal point. For example, Task 101 Boundary Layer Meteorology is a task within the 100 series which is concerned with Model Verification. (Task No. 100.) Task 101.1 Area Climatology is an element of Task 101.

A task specification is given for each task, which states the objective and purposes and scope of the research element concerned. It is intended that professional responsibility for each task be assigned to an individual, who would be charged with accomplishing his task in terms of its objective. The Principal Tasks 100, 200, 300, and 400 in fact would be carried out by the senior personnel of the project as part of their assigned responsibilities. However, the leaders of the subordinate tasks and subtasks (e.g., 101 and 101.1) would be engaged in the day-to-day accomplishment of the work specified, each task leader of a separate task (e.g., 101) being responsible for the product of the subtask leaders (e.g., 101.1) and responsible to the principal task leader (e.g., 100).

Specifications for these tasks follow. Also presented are schedules showing the general timing of the activity within the five-year period. In both cases, the amount of effort that has been used as a basis for planning and costing is indicated in terms of man-years of professional and subprofessional effort.

100 MODEL VERIFICATION

		1972	1973	1974	1975	1976	1977
101	Boundary Layer Meteorology (2.5 p)	xx	xxxx	xxxx	xxxx	xxxx	xx
101.1	Area climatology (.5 p, .5 s)	xx	xx..	....	....	....	..
101.2	Prior diffusion data (.5 p, .5 s)	xx	xx..	....	....	....	..
101.3	Compilation and analysis of upper air data (2.1 p, 2.1 s)	..	.xxx	xxxx	xxxx	xxxx	xx
101.4	Compilation and analysis of near-surface data (2.1 p, 2.1 s)	..	.xxx	xxxx	xxxx	xxxx	xx
101.5	Balloon-tracking experiment (.5 p, 1.5 s)	..	....	.xx.	....	....	..
101.6	Diffusion tracer experiments (.5 p, 1.5 s)	..	....	....	.xx.	....	..
101.7	Weather satellite applications (1.5 p, .75 s)	..	....	....	xxxx	xx..	..
101.8	Forecast models (2 p, 2 s)	..	....	....	..xx	xxxx	xx

Total effort 12.25 man-years--professional (p)
11.00 man-years--subprofessional (s)

100 MODEL VERIFICATION (Continued)

		1972	1973	1974	1975	1976	1977
102	Emission Inventory (5 p)	xx	xxxx	xxxx	xxxx	xxxx	xx
102.1	Emission inventory design (1 p, 1 s)	.x	x...	....	....	....	..
102.2	Collection of emission data for stationary sources (5.25 p, 5.25 s)	..	xxxx	xxxx	(xxxx	xxxx	xx)
102.3	Collection of emission data for mobile sources (.5 p, 5.25 s)	..	.xx(x	xxxx	xxxx	xxxx	xx)
102.4	Emission model for stationary sources (1 p, 1 s)	..	.xxx	xxxx	x...	....	..
102.5	Emission model for mobile sources (1 p, 1 s)	..	..xx	xxxx	xx..	....	..
102.6	Emission source test (6 p, 6 s)	..	..xx	xxxx	xx(xx	xxxx	xx)
102.7	Analysis of status of source controls (1.25 p)	..	.xxx	....	....	....	..
102.8	Emissions inventory of agricultural data sources (.25 p, .25 s)	..	.xx.	....	....	....	..

Total effort 20.25 man-years--professional
19.75 man-years--subprofessional

100 MODEL VERIFICATION (Continued)

		1972	1973	1974	1975	1976	1977
103 Air Quality Measurement (4.25 p)		xx	xxxx	xxxx	xxxx	xxxx	xx
103.1	Data base (.25 p)	.x	x...	....	....	....	..
103.2	Air quality data from local agencies (1.18 p, 4.75 s)	.x	xxxx	xxxx	xxxx	xxxx	xx
103.3	Analysis of air quality and meteorological data acquired by RAPS (4.5 p, 8.5 s)	.x	xxxx	xxxx	xxxx	xxxx	xx
103.4	Analysis of air quality data acquired by aircraft (1.06 p, 2.1 s)	..	.(xxx	xxxx	xxxx	xxxx	xx)
103.5	Fine scale spatial variation of air quality (.75 p)	..	xxxx	xx..	....	....	..

Total effort 12 man-years--professional
15.35 man years--subprofessional

100 MODEL VERIFICATION (Concluded)

	1972	1973	1974	1975	1976	1977
104 Model Calculation and Verification (2.5 p)	xx	xxxx	xxxx	xxxx	xxxx	xx
104.1 Evaluation of selected models (30 p, 70 s)	xx	xxxx	xxxx	xxxx	xxxx	xx
104.2 Model modification and improvement (2 p, 2 s)	..	..xx	xxxx	xxxx	xxxx	xx
104.3 Methodology for determining model accuracy (1.88 p)	..	...x	xxxx	xxxx	xxxx	xx
104.4 On-site computation and data display (2 p)	..	..xx	xxxx	xxxx	xxxx	xx

Total effort 38.35 man-years--professional
72 man-years--subprofessional

200 ATMOSPHERIC, CHEMICAL, AND BIOLOGICAL PROCESSES

		1972	1973	1974	1975	1976	1977
201 Gaseous Chemical Processes (5 p shared with 202)		xx	xxxx	xxxx	xxxx	xxxx	xx
201.1	Hydrocarbon analyses and monitoring (2.06 p, 5.63 s)	..	....	xxxx	xxxx	xxxx	..
201.2	Development of hydrocarbon classifier instrumentation (1.38 p)	xx	xxxx	....	....	....	..
201.3	Total aldehyde-formaldehyde monitoring program (.19 p, .31 s)	..	....	xxxx	xxxx	xxxx	..
201.4	Determination of peroxy-acetyl nitrate (.44 p, .75 s)	..	....	....	xxxx	xxxx	..
201.5	Ammonia monitoring program (1 p, 3.12 s)	..	...x	xxxx	xxxx	xxxx	xx
201.6	CO, SO_2, and NO_2 mass flux measurements (.81 p, .88 s)	..	....	..xx	xxxx	xxxx	xx
201.7	Origin of atmospheric CO (106 p, .75 s)	..	....	....	..xx	xxxx	xx
201.8	Atmospheric odor identification (.75 p, 1 s)	..	....	....	....	...x	xx

Total effort 11.69 man-years--professional
12.45 man-years--subprofessional

200 ATMOSPHERIC, CHEMICAL, AND BIOLOGICAL PROCESSES (Continued)

		1972	1973	1974	1975	1976	1977
202	Atmospheric Aerosol Processes (Shared with 201)	xx	xxxx	xxxx	xxxx	xxxx	xx
202.1	Determination of total nitrate in aerosol samples (.31 p, 1.5 s)	..	....	xxxx	....	....	..
202.2	Determination of total sulfate in aerosol samples (.31 p, 1.38 s)	..	....	xxxx	....	....	..
202.3	Determination of aerosol size-distribution (.69 p, 2.75 s)	..	....	xxxx	xx..	....	..
202.4	The NO_2NaCl reaction in aerosol (.25 p, .13 s)	..	....	.xxx	xxxx	xxxx	xx
202.5	Isotope ratios of sulfate aerosols (.56 p, .75 s)	..	....	....	..xx	xxxx	..
202.6	Organic compounds in particulate material (.75 p, .88 s)	..	....	....	xxxx	xx..	..
202.7	Experimental measurements of deposition velocity (.56 p, 2.5 s)	..	....	....	....	xxxx	xx

Total effort 3.44 man-years--professional
9.87 man-years--subprofessional

200 ATMOSPHERIC, CHEMICAL, AND BIOLOGICAL PROCESSES (Continued)

		1972	1973	1974	1975	1976	1977
203 Other Pollutant Related Processes		xx	xxxx	xxxx	xxxx	xxxx	xx
203.1	Radiation balance modification (.69 p, 1 s)	..	..xx	xxxx	xxxx	....	..
203.2	Visibility reduction in urban and rural areas (.69 p, 1 s)	..	....	....	xxxx	xxxx	..
203.3	Transport of atmospheric odors (.25 p, .25 s)	..	....	....	....	..xx	xx
203.4	Trace metals and toxic trace materials (.69 p, 2.5 s)	..	....	....	xxxx	xxxx	..
203.5	Agricultural chemical distribution (.25 p, .75 s)	..	....	....	..xx	xxxx	xx
203.6	Natural sources of air polluted compounds (1.13 p, .19 s)	..	....	xxxx	xxxx	xxxx	..

Total effort 3.69 man-years--professional
5.69 man-years--subprofessional

200 ATMOSPHERIC, CHEMICAL, AND BIOLOGICAL PROCESSES (Continued)

		1972	1973	1974	1975	1976	1977
204	Atmospheric Scavenging by Precipitation						
204.1	Instrument development for pH and chemical sampling (.50 p, .5 s)	xx	xxxx	....	....	....	..
204.2	Rainfall pH measurement (.53 p)	..	....	xxxx	xxxx	xxxx	xx
204.3	Measurements of rainfall chemistry (.88 p, 5.25 s)	..	....	.xxx	xxxx	xxxx	xx

Total effort 1.90 man-years--professional
5.75 man-years--subprofessional

205	Air Pollutant Scavenging by the Biosphere						
205.1	Chemical content of vegetation (.5 p, 2 s)	..	....	.xx.	..xx	xxxx	..
205.2	Atmospheric pollutant concentrations related to vegetation absorption (.5 p, 1.5 s)	..	....	....	. xx	xxxx	xx

Total effort 1 man-year--professional
3.5 man year--subprofessional

200 ATMOSPHERIC, CHEMICAL, AND BIOLOGICAL PROCESSES (Concluded)

		1972	1973	1974	1975	1976	1977
206 Atmospheric Processes (1.5 p, 3 s)							
206.1	Source factors in pollutant dispersal (.5 p)	..	..xx	xxxx	xxxx	xx..	..
206.2	Terrain and surface roughness effects (.38 p)	..	....	.xxx	....	....	..
206.3	Extraregional and synoptic scale circulation (.75 p)	..	....	...x	xxxx	xx..	..

Total effort 3.12 man-years--professional
3 man-years--subprofessional

300 HUMAN, SOCIAL, AND ECONOMIC FACTORS

1972 1973 1974 1975 1976 1977

301 Human and Social Factors

301.1 Data on epidemiology and health effects (4.5 p, 4.5 s)

301.2 Data on population and land-use characteristics

Continuing low scale effort

301.3 Data on labor force utilization

Total effort 4.5 man-year--professional
4.5 man-year--subprofessional

302 Economic Factors

302.1 Costs of inferior air quality to industrial and general population (4.5 p, 4.5 s)

Continuing low scale effort

302.2 Costs of control strategies

303.3 Data collection surveys of specific effects

Total effort 4.5 man-years--professional
4.5 man-years--subprofessional

400 TRANSFER OF RAPS TECHNOLOGY FOR CONTROL AGENCY APPLICATIONS AND THE FORMULATION OF CONTROL STRATEGIES

	1972	1973	1974	1975	1976	1977
401 Source Inventory Procedures (1 p, 1 s)						
401.1 Techniques for making source inventory procedures						
401.2 Techniques for inventory storage and retrieval						
	..	....	.....	xx..	....	xx
401.3 Techniques for updating the source inventory						
401.4 Relating source inventory to control strategy						

Total effort 1 man-year--professional
1 man-year-subprofessional

400 TRANSFER OF RAPS TECHNOLOGY FOR CONTROL AGENCY APPLICATIONS AND THE FORMULATION OF CONTROL STRATEGIES (Continued)

402 Atmospheric Monitoring

		1972	1973	1974	1975	1976	1977
402.1	Basic network principles (.5 p)	..	....	..xx	....	....	xx
402.2	Criteria for organization and maintenance of observational networks (.5 p)	..	....	xx..	....	....	xx
402.3	Station siting and instrument exposure criteria (.25 p)	..	....	....	xxxx	xxxx	xx
402.4	Methodology for modernization of monitoring networks (.25 p)	..	....	xx..	....	....	xx
402.5	Evaluation of new aircraft measurement techniques (1.63 p)	..	..xx	(xxxx	xxxx	xxxx	xx)
402.6	Evaluation of remote measuring techniques (2.75 p, 3 s)	..	..xx	(xx	xxxx	xxxx	xx)

Total effort 5.89 man-years--professional
3 man-years-subprofessional

400 TRANSFER OF RAPS TECHNOLOGY FOR CONTROL AGENCY APPLICATIONS AND THE FORMULATION OF CONTROL STRATEGIES (Continued)

403 Data Handling

		1972	1973	1974	1975	1976	1977
403.1	Optimize techniques for data acquisition, storage, and retrieval (.5 p)	..	....	..xx	....	....	xx

Total effort .5 man-year--professional

404 Modeling Technology

		1972	1973	1974	1975	1976	1977
404.1	Significance of modeling to the formation of control strategies and their implementation (2.25 p)	xx	xxxx	xxxx	xxxx	xxxx	xx
404.2	Implementation Plan applications (.75 p, .75 s)	..	....	xx..	....	..xx	xx
404.3	Environmental Impact Statement applications (.75 p, .75 s)	..	....	xx..	....	..xx	xx
404.4	Methodology for assessing model validity in control agency operations (.75 p, .75 s)						

Total effort 4.5 man-years--professional
2.25 man-years--subprofessional

400 TRANSFER OF RAPS TECHNOLOGY FOR CONTROL AGENCY APPLICATIONS AND THE FORMULATION OF CONTROL STRATEGIES (Concluded)

	1972	1973	1974	1975	1976	1977
405 Other Significant Factors in Control Strategy Formulation						
405.1 Liaison and interaction with other environmental research programs						
405.2 Techniques of assessing social and economic factors						
405.3 Methodology of assessing operational costs of control strategies	Continuing low scale effort					
405.4 Methodology of assessing resultant costs of control strategies						
405.5 Institutional aspects						

Total effort	4.5 man-year--professional 4.5 man-year--subprofessional

100 Model Verification

Objective

The objective is to test, evaluate, and verify the capability of mathematical simulation models to describe and predict the transport, diffusion, and concentration of both inert and reactive pollutants over a regional area.

Purpose and Scope

The purpose of this series is to investigate the performance of a series of selected mathematical simulation models in circumstances such that as many variables as possible are known. In this way the validity of the model can be determined, or its deficiencies identified, and methods of measuring input or verification data can be optimized for use in subsequent operational applications. The program will investigate emission source assessment, the modeling of admospheric physical and chemical factors, and the methods of verifying and evaluating the operation of the models.

The approach follows two major lines. The first approach is development of the most complete description possible of the meteorological conditions, emissions, and air quality. The second approach applies the appropriate input data to a series of selected models and examines their product against observed data.

The selection of models will follow an evolutionary program, starting with the models ready for immediate testing (FN). Where possible, competing models will be applied to the same data sets. Subsequent tests will be made of improvements of such models on an iterative basis, or in combinations of the most successful features of such models. Major emphasis will be on models relating to the regional scale, but subscale models will be treated in time. First priority will be given to the development of useful tools for reviewing and assessing Implementation Plans. The similar need for Environmental Impact Statements will be given concurrent but subordinate attention. Subsequently, the aim will be to provide fully tested optimum models, the performance of which can be objectively assessed, at each scale for each main class of pollutants.

Consideration will also be given to the role of modeling in connection with air pollution episode prediction.

101 Boundary Layer Meteorology Program

Objective

The objective is to collect meteorological data on the parameters that affect the dispersion of atmospheric pollutants in the St. Louis region.

Purpose and Scope

The purpose of this task is to:

- Provide the meteorological data that are required as inputs to air quality simulation models.
- Obtain data with which to evaluate model computations of meteorological parameters.
- Provide supplemental measurements of meteorological parameters for study of fundamental meteorological processes for subsequent use in the revision of various model components.

The program will commence with the collection of historical climatological and experimental diffusion data for the St. Louis area. Later, data from the various routine RAPS meteorological facilities will be assembled and compiled in a meaningful format using standard metric units; the routine facilities include the basic surface network and the upper air (aircraft and balloon) systems. The program will also include collection and compilation of data from special research programs.

102 Emission Inventory

Objective

The objective of this task is to develop and maintain a comprehensive source inventory.

Purpose and Scope

Numerous components of the Research Plan will require a complete inventory of all emission sources in the study area. This will include both fixed and mobile sources of all major pollutants and perhaps selected minor materials. Emission levels must be described for selected times ranging from yearly to hourly intervals. The inventory should serve in the validation of models, analysis of control strategies, and the investigation of air quality impacts on the human, social, and economic systems of the area.

103 Air Quality Measurement

Objective

The objective of this task is to provide as complete and detailed a description as possible of the distribution (both in space and time) and concentration of air pollutants in the St. Louis region.

Purpose and Scope

The purpose of this task is to provide the data on pollutant distribution necessary for the verification of simulation models of various scales (in space and time) and for various types of pollutant (i.e., both reactive and nonreactive) and various types of source.

Data will be obtained from past records, from routine measurements already being made in the St. Louis area, and from the special measurement networks of the RAPS facility.

104 Model Calculation and Verification

Objective

The objective of this task is to operate, evaluate, and modify a series of air quality simulation models and identify the models that are most suitable for use in formulating air pollution control strategies.

Purpose and Scope

Purposes of this task are to:

- Provide evidence and information as to the effectiveness of a series of selected candidate models so that optimum models can be selected for each aspect of air pollution control.

- Develop techniques of categorizing models in terms of th applicability in respect to both the temporal and spatia resolution and the type or class of pollutants for which they are appropriate.

200 Atmospheric, Chemical, and Biological Processes

Objective

The objective of this series of tasks is to develop an improved understanding of the chemical, physical, and biological processes that are entailed in determining the concentration (the dispersal) of pollutants and the modification of air quality.

Purpose and Scope

Purposes of these tasks are to:

- Investigate in a number of parallel programs the various mechanisms entailed in the transport, transformation, and removal of pollutants not now well understood.
- Develop techniques of describing (or better describing) such mechanisms so that they can be accounted for in existing models or models to be developed to accommodate them.
- Identify conditions or processes that are significant in formulating control and abatement strategies to provide air quality amelioration.

The approach follows three major lines. The first approach is the acquisition of a better quantitative knowledge of processes already recognized as significant but that have not been adequately described for modeling purposes. The second approach is development of a better understanding of the significance of various processes in terms of adequately modeling complex air quality factors. The third approach is investigation of pollutants and pollutant processes that are not yet considered in control strategies, and assessment of their importance so that appropriate strategies can be formulated.

201 Gaseous Chemical Processes

Objective

The objective of this task is to develop an improved understanding of the gaseous chemical processes that are important in determining the concentrations of air pollutants and in the design and specifications of simulation models dealing with the transport of gaseous pollutants.

Purpose and Scope

Purposes of these tasks are to:

- Investigate through a number of discrete but interrelated projects various mechanisms that are important in the transformation and scavenging of gaseous air pollutants.

- Carry out specific sampling programs designed to better describe the concentration field of various important pollutants that are not covered by the regular monitoring system.

- Develop special measurement techniques and automatic instrumentation that can be used to describe in more detail the atmospheric concentration fields of specific air pollutants.

- Relate the processes and conditions observed in the field program to existing or potential simulation models and to abatement strategies.

202 Atmospheric Aerosol Processes

Objective

The objective of this area of the program is to develop improved understanding of, and expanded data on, the nature of atmospheric urban aerosols and the processes that are important in determining (1) the chemistry and concentrations of these materials and (2) the application of this information in the design and specifications of simulation models dealing with the transport and transformation of atmospheric aerosols.

Purpose and Scope

The purposes of this task are to:

- Investigate through a number of individual but interrelated projects the various mechanisms that are important in the formation, transformation, and scavenging of atmospheric aerosol particles.

- Carry out specific sampling programs designed to better describe both the chemistry and concentration fields of various atmospheric aerosols and to relate these measurements to the routine measurements obtained by the regular monitoring system.

- Conduct a coordinated program of gaseous and particulate sampling experiments with the goal of describing the specific mechanisms by which atmospheric aerosol particles are formed from gaseous contaminants.

- Develop special measurement and instrumentation techniques that through automatic operation can be used to describe in more detail the atmospheric concentration fields of specific particulate materials.

- Relate the processes and conditions relative to the formation and transport of atmospheric aerosols to existing and future simulation models and to abatement strategies.

The individual projects within this program area fall into three general categories: (1) special monitoring programs for specific aerosol materials, including size distribution studies, aerosol chemistry, and studies of the interaction of aerosols and gaseous contaminants; (2) development of instrumentation and analytical techniques to improve the effectiveness of aerosol monitoring programs and to provide the data necessary for simulation modeling applications; and (3) special transport and scavenging research studies aimed specifically at delineating atmospheric processes that serve to determine the characteristics of atmospheric aerosols in urban and rural areas.

For the most part, research in atmospheric aerosols is hampered by the fact that relatively little automatic instrumentation can be used to obtain detailed data on the chemical constituents that make up the atmospheric mass. As a result, most of the programs are based on a gathering of specific field samples followed by a period of laboratory analysis to determine the nature of the collected samples. This means that the samples generally have poor time resolution because of the length of time necessary to collect enough material for adequate analysis, and because the number of samples that can be collected practically is limited because of lack of available manpower and laboratory facilities. If suggested instrumentation development is successful, some of these problems may be ameliorated; however, since the suggested instrumentation is not new but has been recognized for a number of years, a higher degree of hope cannot be expressed for the successful resolution of this instrumentation design problem.

203 Other Pollutant Related Atmospheric Processes

Objective

The objective of this task is to develop an improved understanding of a wide range of atmospheric processes that are important in understanding the transport, transformation, and final removal processes of atmospheric pollutants.

Purpose and Scope

The research effort will investigate through a number of individual research projects various atmospheric processes and mechanisms that are related to the understanding of pollutant distribution over an urban and rural area. These atmospheric processes cover a range of applicable conditions and have not been readily classifiable into other areas of this research prospectus.

The individual research projects carried out within this section, while dealing with specific and identifiable objectives, will generally relate in some detail to one or more of the other research projects described in other parts of this Prospectus.

204 Atmospheric Scavenging by Precipitation

Objective

The objective of this task is to develop an improved understanding of the nature of precipitation scavenging of atmospheric pollutants and to relate these processes to other environmental factors such as water quality.

Purpose and Scope

Purposes of this task are to:

- Investigate through sampling and analytical projects the extent and processes of precipitation scavenging of atmospheric pollutants.
- Relate the observed precipitation scavenging processes to pollutant emissions and downwind pollutant concentration patterns and to develop models by which the impact of precipitation scavenging can be included in simulation modeling of the transport and dispersion of atmospheric pollutants.
- Develop special instrumentation where necessary to sample and analyze precipitation for scavenged air pollutants.

The individual projects within this program area include instrument development and sampling programs directed toward the measurement of precipitation chemistry. After analytical results are available, the data will be related to air quality concentration patterns and to meteorological conditions to develop a better understanding of the nature of the precipitation scavenging process.

205 Air Pollutant Scavenging by the Biosphere

Objective

The objective of this task is to develop an improved understanding of the relationship of the biosphere to air pollutant dispersion and transport and in particular the effect that the biosphere has on the scavenging of air pollutants from the atmosphere.

Purpose and Scope

Atmospheric transport and dispersion processes serve to bring air pollutants in contact with large amounts of biological material, and it is known that plants are effective absorbers of trace chemical materials from the atmosphere. This program will conduct projects designed to provide quantitative estimates of the scavenging mechanisms that are effective within the biosphere in removing air pollutants from the atmosphere.

The research effort also will relate the scavenging processes observed in the field to existing or potentential simulation models and to an evaluation of the interaction between air pollution and the biosphere.

Purpose and Scope

During its life cycle, vegetation has a large intake of atmospheric air and this forms a very large part of the plant life cycle. During the intake of atmospheric air, pollutants are also brought into the plant where they are retained; in addition, plant surfaces are exposed to the flow of air, and as such they provide areas where pollutants may be deposited or absorbed even though not being brought directly into the plant tissues. These are loss mechanisms that in some cases have been shown to be significant and to cause measurable changes in the ground level concentrations of specific air pollutants. This research project will attempt to quantify these absorption or removal mechanisms.

206 Atmospheric Processes

Objective

The objective of this task is to provide an additional understanding and description of physical atmospheric processes not already accounted for in generalized boundary layer meteorological modeling.

Purpose and Scope

The research for this task will extend the capability of general boundary layer theory to include anomalous physical factors of significance in the dispersal of pollutants. These factors include smaller scale phenomena, such as the effects of special emission conditions (i.e., at the stack) on the behavior of effluent plumes, or the local variation of surface roughness (i.e., different terrain or land use conditions) on air flow--or larger scale phenomena, such as the influence of extraregional features or synoptic scale circulations on the air flow characteristics within the Region.

Inputs will be obtained from other ongoing research programs or from special studies conducted within the RAPS program. Consideration will be given to conducting physical modeling studies in the laboratory where appropriate.

300 Human, Social, and Economic Factors

Objective

The objective of the tasks in this series is to develop a better understanding of factors of significance to the design of improved control strategies in the urban/rural complex, including health and economic effects and the role of land use and community planning.

Purpose and Scope

Purposes of this research program are to take advantage of the unique facility the RAPS organization provides to collect data on human, social, and economic factors in an economical and well focused manner to complement the purely physical aspects of RAPS, for the subsequent formulation of improved control strategies. The data will provide the additional basis that will be needed to apply the lessons learned in the RAPS in improved control strategies that are effective and acceptable in terms of priorities, costs of implementation, and value of results.

The resources of field teams, data analysts, and data processing facilities will be made available to collect human, social, and economic data identified as significant to the purpose noted. Data will be collected either by adding elements to other data collection surveys or by initiating special surveys. Steps will be taken to ensure that the data are compatible with the physical data collected so that interpretation and evaluation of the data on effects will be facilitated.

301 Human and Social Factors

Objective

The objective of this task is to provide a data base of relevant information on human and social factors that can be used in RAPS and in developing methodologies for using such data in other areas.

Purpose and Scope

Purposes of the task are to:

- Take advantage of the data handling and analysis capabilities of a RAPS organization to gather data on epidemiology, mortality, and the like.

- Determine population concentrations and land use characteristics.

- Provide information on the utilization of the labor force and its skills and mobility.

302 Economic Factors

Objective

The objective of this economic research is to provide a data base of relevant information on economic factors that can be used in RAPS and in developing methodologies for using such data in other areas.

Purpose and Scope

The purpose of the task is to take advantage of the data handling and analysis capabilities of the RAPS organization to gather data on the various costs of air pollution to the industrial and general population (e.g., depression of property values, damage to property, loss of productivity due to sickness) and also the cost of air pollution control strategies, in terms of both plant modification and increased costs of production.

400 Transfer of RAPS Technology for Control Agency Applications and the Formulation of Control Strategies

Objective

The objective of this series of tasks and supplies is to develop improved technology that can be applied in local and regional control agency operations, including techniques for emission inventories, air quality and meteorological measurement, data handling and analysis, and the objective assessment of control strategy effectiveness.

Purpose and Scope

The purpose of this research area is to ensure that the knowledge and technology developed in the RAPS is transferred widely to the air pollution control community at large as early and effectively as possible. This requires passing on improvements and innovations in the techniques of measurement, data handling, utilization in a direct form. It also includes the conversion and distillation of the knowledge and technology developed in RAPS in the specific test region to a generalized form, so that it can be applied in other regions and for other problems with minimum difficulty. Above all, however, this task provides the basis for the development of improved control strategies, by national, state and local agencies.

The approach follows four major lines. The first approach is development and description of techniques and criteria by which the basic air pollution factors can be assessed and monitored on an operational (as distinct from research) basis. Particular attention will be given to identifying and developing new techniques of monitoring atmospheric and air quality conditions on extended scales appropriate to regional and subregional control strategies so that the costs may be minimized. The use of aircraft and remote probing techniques either from such aircraft, or from the surface are especially suited to this purpose and every attempt should be made to advance their applicability.

The second approach is the provision of tested, effective simulation models, suitable for operational use on a generalized basis (that can be readily modified and adapted), for other areas and conditions. The third approach is development of a methodology for assessing the validity (in terms of confidence, accuracy, and precision) of the preferred models, for varying degrees of input data quality. The fourth approach is to provide methodologies for determining and assessing other factors such as health effects and economic costs and benefits relevant to the formulation of improved control strategies.

First priority will be to provide data applicable to current data resources, deficient though these may be, with emphasis on the optimum methods of providing more complete data for input to models and for air quality monitoring and model verification purposes. The needs of the states and local authorities (and EPA) to improve and extend Implementation Plans will be treated first, with concurrent although subordinate attention to Environmental Impact Statement requirements. First milestone will be the achievement of interim capabilities for these purposes. Thereafter, a more complete and detailed facility will be developed, covering all aspects of control strategies formulation then current and capable of extension to other pollutants and the like as the need arises.

401 Source Inventory Procedures

Objective

The objective of the task is to provide guidelines for the development and maintenance of source inventories as derived from the experience in the Regional Study.

Purpose and Scope

The source inventory for the Regional Study is likely to be the most comprehensive such inventory yet developed. The methods by which the source data are acquired and updated, and the manner in which the inventory is organized, stored, and retrieved should prove to be of considerable value to others faced with the task of preparing sources inventories. Accordingly, this component of the Research Plan includes efforts required to prepare guidelines and reports for the benefit of others, covering the techniques developed in the Regional Study for the management and use of source inventories.

402 Atmospheric Monitoring

Objective

The objective of this task is to improve the technology and technique of monitoring atmospheric conditions, particularly on extended scales, so that control strategies can be better implemented.

Purpose and Scope

The purpose of this task is to make available for use in all types of air pollution control operations as early as possible, the lessons learned and the techniques developed in the RAPS.

Basic principles for designing measurement networks for control agency operation and criteria for the siting of monitoring stations and instrument exposure, will be developed on the basis of experience with the RAPS data collection network.

Criteria for the organization and maintenance of extended networks of measuring instruments, with special reference to calibration and standardization, will be established. This research effort also will develop a methodology by which newly acquired data, using new techniques, can be related to older data so that the value of the latter is fully realized, even if strict continuity is not maintained.

Remote probing systems will be tested and evaluated, in comparative trials as candidate systems become available. Such tests will be conducted in conjunction with both the standard RAPS data collection system and special programs that provide especially detailed knowledge of meteorological conditions or the concentration of pollutants.

In particular, use will be made of helicopter soundings and other aircraft acquired data. The application of remote probing techniques from aircraft, as well as of aircraft in situ measuring techniques, is an additional and important study subject.

403 Data Handling

Objective

The objective of the data output task is to develop optimum techniques for acquiring, storing, and retrieving data on an extended scale for use in air pollution control agency operations.

Purpose and Scope

The purposes of the task are to:

- Make available the lessons learned and techniques developed in RAPS regarding the handling of all types of data collected and used in an extensive monitoring network and emission inventory.

- Develop and publish Standard formats as used in RAPS that are suitable for general use.

- Develop and publish manuals and computer programs for all major types of data collection and initial processing, suitable for use in air pollution control agency use.

- Provide guidelines on quality control procedures for use in collecting data.

404 Modeling Technology

Objective

The objective of this task is to provide the best available modeling capability for use in operation in air quality management.

Purpose and Scope

The purpose of this task is to extract from the research and experience of RAPS a number of models that have been tried and demonstrated and to show how these can be adapted and used for a range of specific operational requirements in an optimum fashion.

A most important major task is to evaluate the significance of modeling techniques to the formulation of control strategies and their implementation. This entails an assessment of the accuracy and precision of the models output as a function of the degree of completeness of the input. Given that the resources for data collection and monitoring in the general case will be far less complete than those for RAPS, it will be necessary to analyze the way in which limitations of the input can compromise the output of the models. Any shortcomings or uncertainties of the predictions derived from the models must be fully assessed and understood in terms of the control strategies based on them--especially where such strategies have significant economic or social impacts.

In addition to models suited to regional areas in general for the range of significant pollutants, special attention must be paid to providing suitable models for use in formulating or checking Implementation Plans, as well as for use in Environmental Impact Statements, and the requirements of air pollution episode prediction.

For all these purposes it will be necessary to:

(1) Select and publish a series of models relating to appropriate scales or pollutants in a form in which they can be readily applied in an operational role.

(2) Develop and provide a methodology for assessing the sensitivity of such models to practical limitations--such as the quantity or quality of input data, and qualifying topographical features.

(3) Develop and provide a methodology for measuring the accuracy of predictions based on such models, using either existing or specially provided (but limited) additional measurement facilities.

In general the detailed tasks, covered within the 404 series are scheduled well along in the Research Plan at a relatively low level of effort. Accordingly, their ultimate detailed content tends to be somewhat more speculative than tasks presented elsewhere in the Research Plan, so that presentation of their content in detail does not appear warranted at this early time.

405 Other Significant Factors in Control Strategy Formulation

Objective

The objective of the other tasks concerned with strategy formulation is to ensure that all knowledge and experience acquired under the RAPS program is made available for use by the air pollution control community in general and those concerned with formulating improved control strategies in particular.

Purpose

The purpose of these other efforts is to take care that both during the RAPS program and at its conclusion, fullest advantage is taken of other research in progress (both by EPA and other agencies) and also that the products of RAPS not directly connected with its principal objectives nevertheless are made available in appropriate form to potential users. Five principal components are involved.

(1) Liaison and interaction will be required with other research programs, both inside EPA and in other agencies, particularly those being carried out in the St. Louis area, such as METROMEX.

(2) Techniques should be developed to assess and evaluate social and economic factors in control strategy formulation, using as a base the data collected in 302 and 302.

(3) A methodology for assessing operational costs of control strategies should be developed for use in areas where available data are less complete than in the RAPS area.

(4) Similarly, the development of a methodology for assessing the resultant costs in terms of lost production and increased production costs of proposed strategies will be appropriate.

(5) Investigations on the basis of study and experience in the St. Louis region should be carried forward to identify the interaction of local government and other institutional aspects that are relevant to the formulation of effective control strategies and their enforcement.

In general the detailed tasks, covered within the 405 series are scheduled well along in the Research Plan at a relatively low level of effort. Accordingly, their ultimate detailed content tends to be somewhat more speculative than tasks presented elsewhere in the Research Plan so that presentation of their content in detail does not appear warranted.

VI THE FACILITY

Rationale

Basic Operations

Since the RAPS research and development program is planned as a five year integrated operation, it is discussed in this chapter in terms of a general time sequence of project initiation. As a point of departure, it is assumed that the total RAPS program will be initiated in July 1972 and that research operations can be started at this time.

The RAPS program is such that two types of field operations are necessary. One type of field operation is the research expedition, characterized by the fact that it has a limited or single objective and requires relatively short periods of field operation for data acquisition. The second type of field operation is the ongoing research study, characterized by a need for routine data acquisition over an extended period of time. The four basic RAPS task areas include projects in both field operational categories; however, since the provision of a data acquisition network for routine, ongoing research operations results in a major investment of both funds and personnel, the needs for such an investment will be examined.

Basis for Monitoring Network

A major objective of the RAPS program is the verification and evaluation of simulation modeling techniques. To fulfill the RAPS goals, this verification process must include much more than a statistical comparison of observed and model-predicted pollutant concentrations in the area around a source region. The RAPS program must also provide the opportunity to evaluate separately the several submodel routines that are component parts of all simulation modeling systems. The comparison of the submodel routines, e.g., the transport wind direction field, with the actual conditions prevailing during the verification test operation, will permit the identification of specific weaknesses in the simulation programs and procedures. Follow-up research leading to modifications in the simulation procedures can then be conducted to improve and extend the candidate simulation techniques.

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This necessity to be able to understand why a candidate simulation model produces a given result requires detailed knowledge of the meterological, air quality, and emission fields in the test area. One way to obtain detailed meteorological and air quality data is through establishment of a comprehensive network of observational stations throughout the verification test area. Verification and data acquisition studies carried out to date usually have been limited either by having to use existing monitoring network data where the network had not been established to meet the needs of a verification program or by establishment of a special test program where funding and other practical problems limited the amount and time-span of the data acquisition program.

Since the objective of the RAPS program is the verification of a variety of current and future candidate model systems, it cannot be adequately carried out if the verification data acquisition system is not geared specifically to the range of verification problems that the RAPS program is expected to solve. Thus the RAPS verification data acquisition system must: (1) include detailed meteorological and air quality measurements, (2) give adequate coverage over distances of up to 150 km from the source area, and (3) provide these data on average ambient conditions for periods as short as one hour and as long as one year. In this context, detailed air quality data include ambient air concentration information for pollutants that are covered by current and proposed air quality criteria, including but not limited to SO_2, Co, No, NO_2, oxidants, hydrocarbons, suspended particles, lead aerosols, and fluorides, because model verification studies are expected to be concerned with these individual pollutants.

When all these factors are considered, the installation of a sophisticated monitoring system is the optimum way to meet the needs of the RAPS model verification program for regionwide air quality and meteorological data.

The RAPS program also is directed toward providing new data and an improved understanding of atmospheric chemical reactions, pollutant scavenging, and other atmospheric processes. Such a goal also requires a basic foundation of detailed data on atmospheric pollutant concentrations that a monitoring system can provide most effectively. The needs of this program are generally parallel to the basic components needed for the model verification program. The planned monitoring system design incorporates some components and design features that are specifically directed toward supporting chemical transformation studies and scavenging projects.

The RAPS program is also specifically charged with improving available technology in the area of air monitoring networks through the development of optimum designs and operational techniques.

Thus establishment of an air quality and meteorological monitoring network is justified on the basis of the requirements that have been placed on the RAPS program in the areas of air pollution simulation model verification, atmospheric transformation processes, and improved control agency technolgoy. Because of the area to be covered and the number of variables that are to be monitored, a telemetering, computer-controlled network has been designed for this RAPS program. Instrumentation components are, in general, the newer designs now being specified for local and regional use, although they have not generally been placed into general service by local control agencies. The proposed research program is based on the monitoring network being operational about 18 months after the RAPS program is initiated.

The special objective, expedition-type, data acquisition program can be fairly closely specified--both in terms of the type and nature of the data collected and the periods over which such data are needed. The more general, comprehensive data collection program, designed to meet the known, anticipated, or potential requirements of a number of studies, cannot be so closely specified. In proposing to maintain a continuous data collection facility to meet the general need, it is recognized that a danger exists accumulating large masses of data that could have little or no use; therefore, great care must be taken in setting up the general data acquisition program to avoid wasted costs and dissipated effort. However, some redundancy is both inevitable and desirable in a data acquisition program of this type.

To ensure that adequate data are available for investigations that cannot be defined a priori or to be sure that no data of a specific type are missed or imperfectly collected, it will be necessary to make extensive and continuous collections that will include some material that may be used quite infrequently; their importance in achieving the program objective may nonetheless be great. This principle is well recognized in many observational activities--especially where weather is involved. With modern data acquisition and processing systems, however, the unit cost of collecting additional data decreases rapidly once the initial investment in equipment and in setting up procedures has been made. Indeed, if data are to be collected at successive times throughout the year, even if considerable intervals can be anticipated, it is almost certain that little or no saving in overall costs could be made by operating intermittently, since the costs of shutting down and opening up would outweigh any minor savings by not running continuously on a routine basis.

The St. Louis Regional Monitoring Network

The St. Louis facility is conceived as consisting of a system of air quality and meteorological instrument stations established within an area roughly enclosed by a circle of 100-km radius with the St. Louis arch as its center. A central support facility is also planned that includes data-handling and processing equipment, office and laboratory space and repair and maintenance shops. Most instrument stations are expected to be linked to the central facility by telephone circuits to permit automated remote data recording at the central facility.

The St. Louis facility is planned as the basic instrument system of the Regional Study. It could be operated in a fully continuous or part-time mode to develop a comprehensive data base of air quality and meteorological conditions. Detailed statistical and other analyses then could be performed as required by the various elements of the Research Plan. During the field studies and data-acquisition efforts covered in the Research Plan, the facility would be operated to support these efforts most effectively. Support could include equipping the instrument stations with additional instruments, locating transportable stations as specified by the research group, preparing and operating specialized data processing programs, and providing instrument and experimental technician support.

Six types or classes of instrument stations are included in the facility. These range from the permanently installed Class A_1 stations with 30-meter instrument towers equipped with a full complement of air quality and meteorological instruments to the trailer-mounted Class C_2 stations having no air quality instruments and a single meteorological instrument. The principal characteristics of the stations are summarized in Table 1.

Stations of Classes A_1, A_2, and B_1 are visualized throughout the Regional Study as permanently sited, although this is certainly not a fixed requirement. These stations are considered the basic units for the long term observational program. The Class B_2 stations have the same instrument complement as the Class B_1 stations, but they are transportable units housed in trailers. The Class C_1 stations are denoted as transportable units since a trailer is used for instrument installation. However, the fact that the station is equipped with a 30-meter tower, suggests less frequent movement than the other transportable stations.

The Class C_2 stations are a hybrid unit. As part of the central facility they include the trailer unit, tower, and digital data terminal equipment. They will be used by the various groups carrying out field experiments and data-gathering efforts associated with the various research efforts presented in Part II. Additional instrumentation required at a

Table 1

CLASSIFICATION OF THE REGIONAL STUDY INSTRUMENT STATIONS

	Class of Station					
	A_1	A_2	B_1	B_2	C_1	C_2
	Number of Instruments					
Air quality instruments						
Carbon monoxide - methane - hydrocarbon	1	1	1	1	--	--
Hydrogen sulfide-sulfur dioxide	1	1	1	1	--	--
Total sulfur	1	1	--	--	--	--
Ozone	1	1	1	1	--	--
Nitrous oxide - oxides of nitrogen	1	1	1	1	--	--
Nephelometer	1	1	1	1	--	--
Carbon monoxide (NDIR)	1	1	--	--	--	--
Hi-vol sampler	2	2	2	2	--	--
Meteorological instruments						
Temperature	1	1	--	--	1	--
Wind direction and speed	3	3	1	1	3	1
Pyranometer	1	--	--	--	1	--
Pressure transducer	1	--	--	--	1	--
Mercury barometer	1	--	--	--	1	--
Net radiometer	1	--	--	--	1	--
Dew point hygrometer	1	--	--	--	1	--
Rain - snow gauge	1	--	--	--	1	--
	Station Characteristics					
Tower height						
30-meter	x	x			x	
10-meter			x	x		x
Data recording						
Remote	x	x	x	x		
Local					x	x
Mobility						
Fixed	x	x	x			
Transportable				x	x	x
Total quantities	9	8	24	8	4	24

Class C_2 station in support of these field efforts would be considered a part of the particular research effort rather than of the St. Louis facility. Accordingly, the instrumentation of the Class C_2 stations would be expected to vary widely during the Regional Study. This same concept would also apply to instruments added to other classes of stations set up in support of field activities.

Data acquisition and handling in the St. Louis facility are expected to be automated to the greatest possible extent. Instrument observations at all but the Class C_1 and C_2 stations are planned to be transmitted by telephone circuits to the central facility for automatic computer-controlled recording. The Class C_1 and C_2 stations are currently planned to have local data-recording facilities, but further analysis might indeed indicate these also could use a remote reporting capability efficiently.

The digital data terminal equipment of the remotely reporting instrument stations interrogates each air quality and meteorological instrument at a predetermined frequency, converts the analog instrument output to its digital equivalent, and stores the digital data in a relatively small-capacity magnetic core memory. On command from the central facility, expected to occur at about 15-minute intervals for each station, the stored data are automatically transmitted to the central facility. Calibration curves of all instruments are stored in the data-processing system at the central facility so that immediate conversion is made from the digital data format to engineering units for archiving.

Each air quality and meteorological instrument would be equipped with a solid-state, nonerasable memory unit to serve as an identifier of each instrument. A unique serial number, or equivalent, of each instrument would be coded into the identifier with the identifier then mounted on the instrument. At each interrogation of each instrument, the identifier would respond immediately before or after the instrument reading was acquired so that the instrument reading and its identification would always be together. This procedure should result in an absolute minimum of data ambiguity and erroneous interpretation and is judged to be far superior to customary procedures using instrument log books and other manual methods.

The principal data-handling and processing function at the central facility would include the recording and archiving of all instrument station data and other field and experiment information. The archival tapes would be forwarded to Research Triangle Park or other EPA installations as appropriate or to contractors for use in their analyses on a particular research project. Minimal detailed data analysis is expected to be carried out at the St. Louis facility, and the electronic data-processing equipment is sized accordingly. Selected research experiments may require limited data processing during their execution, and the St. Louis facility should have the required capability. But large scale data processing covering data acquired over a period, say, of the spring and summer seasons would be expected to be undertaken on the larger computer systems existing at the Research Triangle Park and elsewhere.

The instrument stations constituting the St. Louis facility are planned to be located within a circle of about a 100-km radius centered generally on the St. Louis arch. Eight Class A stations are symmetrically located around the 100-km circle, while an additional eight are symmetrically deployed on a 40-km square with the arch as its center. The final Class A station is planned at the arch itself. Depending on actual conditions at the arch site, advantage might well be taken of nearby taller television or other towers.

The Class B_1 stations are planned for installation on a uniform square grid about the arch with station spacings of about 12 km.

The remaining stations are considered to be transportable and would be deployed as required to support a given field data-acquisition program. This is particularly true for the Class C_2 stations. The stations other than the Class C_2 would generally be expected to provide the overall or ambient observations of air quality, meteorological, and other parameters of interest on an areawide basis. Observations in detail within a specific smaller area would be carried out by deployment of the Class C_2 stations within the area of interest.

Since the precise station locations will depend on the availability of suitable sites, the pattern presented here must be regarded as tentative. Instrument station sites must be selected with respect to several important factors, including freedom from unique or overriding micrometeorological effects, general absence of nearby significant pollutant sources, convenient access to electric power and communication utility services, and free access at all times. Only a detailed field survey will reveal sites possessing these and other necessary characteristics.

In addition to the routine surface-based data acquisition network, upper air measurements of meteorological and air quality parameters will be undertaken both on a routine and special task basis. The primary meteorological system will use METRAC or an equivalent precision automated balloon-tracking system. With METRAC, it is proposed that vertical soundings of wind, temperature, and possibly humidity, pressure, and/or net radiation be made at a four- to six-hour interval at a minimum of two stations (typically urban and rural). The system has the capability to track simultaneously up to six different balloons (both vertically-rising and constant-level) providing detailed wind information and data from four different sensors on each balloon. As such, it can also support a variety of special purpose programs. Air quality data will be obtained on a regular basis through the use of a helicopter monitoring system. Flights will be made on two or three days per week with two (three-hour) flights each day. In addition to the air quality observations, supplemental meteorological data, such as radiation measurements, will also be made. Fixed-wing aircraft are recommended for use only on a nonroutine basis and in support of special-task programs.

VII MANAGEMENT AND SCHEDULING

Introduction

The Regional Study will constitute the largest and most comprehensive scientific investigation and analysis of the phenomenology of air quality and pollution yet undertaken. Field data describing air quality, meteorology, and other pertinent factors will be obtained by an instrument and data processing system unprecedented in the study of air pollutants. This critically important effort will require the most careful planning and management both before and during its execution to ensure effective utilization of the facilities and personnel assigned to the Regional Study and the most appropriate expenditure of funds.

This chapter of Part I presents findings largely applicable to scheduling, management, and staffing of the St. Louis facility. It is certain that the scope of the Regional Study is such that continual review and modification will be required of all the estimated schedules, costs, and other factors presented in this Prospectus. This tends to be of particular importance in regard to the estimated activation schedule, since many policy and design considerations are present, not all of which can be anticipated or evaluated at this time. Moreover, several important aspects of the schedule and perhaps certain costs will depend on the actual conditions found to exist in St. Louis after authorization of the Regional Study. Accordingly, the planning factors presented are regarded as having an accuracy and reliability suitable for the planning purposes of this Prospectus and for the purpose of providing a working format for additional and more detailed planning efforts.

Facility Activation Schedule

The activation schedule of the St. Louis facility is viewed as having three principal components. The first covers the design, installation, and shakedown and acceptance of two prototype instrument stations. The second includes the activation of all Class A and B stations. The third provides for completion of the Class C stations.

The overall schedule adopted for the St. Louis facility activation will depend on a number of critical factors. These include the urgency for initiation of the research experiments requiring the full instrument system and the magnitude of funds allocated for the Regional Study. Also, a number of alternative methods or rationales may be used to develop the geographical pattern of station location. In one case all stations could be installed in a continuous sequential schedule on the basis of currently available emission source data and air quality and meteorological information. In the other case, stations might be installed at a far lower rate, so that the first group of stations would be allowed to acquire significant air quality and meteorogical data from which possible guidance would be derived for the second group, and so on. The basic concepts of scheduling under each procedure should be essentially the same; the continuous schedule has been selected for purposes here.

The design installation, and operational acceptance tests of the instrument prototype stations is estimated to require on balance about 44 weeks. The critical path through the scheduling network consists almost exclusively of the digial data terminal equipment. This situation is caused primarily by the fact that all air quality and meteorological instruments are considered to be standard catalogue items with relatively short procurement times, whereas the digital data terminal equipment consists of a combination of standard and specially designed equipment. The latter group of digital data equipment causes much of the length of the critical path, especially when combined with the design decisions associated with the telephone communication system design.

Two alternatives have been identified for scheduling the activation of all Class A and B stations. One alternative is to delay all activation until the prototype station has been thoroughly tested and all components have been accepted. Scheduling on this basis is estimated to require an additional 33 weeks for final station completion, or 77 weeks for full activation of the St. Louis facility.

The other alternative is to initiate activation before prototype station acceptance. In this case, activation could be started at the end of the acceptance tests of the prototype station air quality instruments, which is estimated to occur 23 weeks after authorization of the Regional Study. Since, as noted above, the prototype station critical path is estimated at 44 weeks, initiation of system activation after prototype operation of the air quality instruments is likely to achieve considerable economies in time. Such overlapping is estimated to bring full system operation 18 weeks earlier than the former schedule, with completion at 59 weeks.

Moderate risk is estimated to exist in continuing station activation without full completion of the prototype stations. This risk arises with the design of the equipment linking the meteorological and air quality instruments with the bulk of the digital data equipment. However, in view of the inherent flexibility of digital data circuitry designs and equipment, any incompatibilities revealed in prototype station design undoubtedly can be corrected in the digital data equipment before installation in the remaining stations.

The Class C station essentially can be scheduled independently of the other stations, since their digital data terminal equipment provides for local rather than remote recording. The Research Plan indicates a need for approximately ten Class C_2 stations about eight months after authorization of the Regional Study with the remainder following soon thereafter. Accordingly, initiation of the digital data equipment procurement cycle can be initiated ten weeks after authorization with station activation beginning 12 weeks later. At an activation rate of one per week, all stations will be completed in 51 weeks after authorization with the first ten available 33 weeks after authorization.

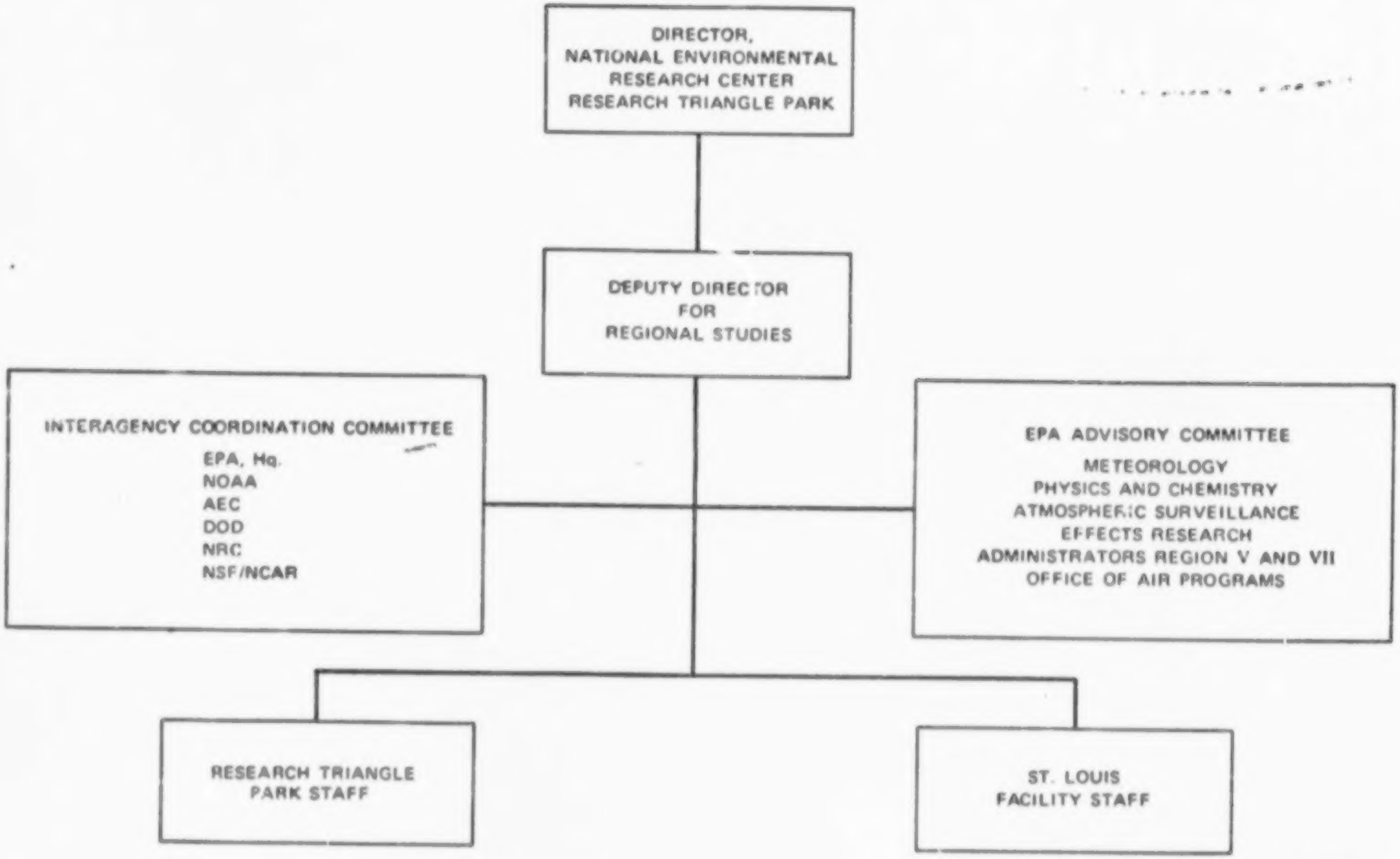
These activation schedules are based on the assumption that the central facility and all instrument stations sites have been acquired before the time of scheduled station activation. This is regarded as a most critical assumption, and the lack of instrument sites could indeed cause serious delay in system activation. Immediate field survey initiation following authorization of the Regional Study and preferably before, appears essential to permit station activation to proceed on schedule.

Permanent Management and Staffing

Of the 54 permanent personnel assigned to the Regional Study, nine are estimated to be located at Research Triangle Park and 45 in St. Louis. The organizational structure is summarized in Figure 5.

The significance of the Regional Study is such that the establishment of the position of Deputy Director for Regional Studies appears appropriate. The Deputy Director will report directly to the Director, National Environmental Research Center, Research Triangle Park. The Deputy Director will be supported by three staff groups as follows.

- Office of Programs--This Office will provide EPA coordination, budgeting, and planning support throughout the study. A minimum of two professionals are estimated to be required.


DIRECTOR,
NATIONAL ENVIRONMENTAL
RESEARCH CENTER
RESEARCH TRIANGLE PARK
DEPUTY DIRECTOR
FOR
REGIONAL STUDIES
INTERAGENCY COORDINATION COMMITTEE
EPA, Hq.
NOAA
AEC
DOD
NRC
NSF/NCAR
EPA ADVISORY COMMITTEE
METEOROLOGY
PHYSICS AND CHEMISTRY
ATMOSPHERIC SURVEILLANCE
EFFECTS RESEARCH
ADMINISTRATORS REGION V AND VII
OFFICE OF AIR PROGRAMS
RESEARCH TRIANGLE
PARK STAFF
ST. LOUIS
FACILITY STAFF

SA-1365-13

FIGURE 5 SUMMARY ORGANIZATION OF THE REGIONAL STUDY

- Office of Interagency Coordination and Technology Transfer--This Office will be charged with providing full coordination among all agencies dealing with problems of air pollution. The broad scope of the Regional Study is such that programs of other organizations and agencies will be continually monitored to determine possible interfacing points, cooperative ventures, and other modes of joint operation. Conversely, the Office will have the principal task of advising other agencies of the programs planned for the Regional Study to again promote full cooperation. The Office will have the additional responsibility of continual review of findings developed in the Regional Study for application to other areas and experimental efforts. The Office is estimated to require one professional in the early phase of RAPS, increasing to three professionals after the first year.

- Office of Research Operations--This Office is expected to provide the very important technical link between the research divisions at Research Triangle Park and the St. Louis facility. The Office would consist of at least one representative from each division but would remain administratively within the division. The chief responsibility of each representative would be to organize and supervise the research programs within his division that will make use of the St. Louis facility. He will be responsible for data acquisition quality control, as well as for execution of the subsequent analysis. Three professionals are estimated to be required in this Office in addition to the Division representatives.

The St. Louis staff will be largely responsibile for the operation of the facility and support of the field research experimental effort. The staff consists of nine professionals and 36 nonprofessionals with 17 of the nonprofessionals engaged in instrument station maintenance and calibration. The professional staff includes the following:

- Facility Director--The facility director will be responsible for all St. Louis operations, reporting to the Deputy Director for Regional Studies.

- Research Coordinator--The research coordinator provides all logistic and facility support to special research groups carrying out field data gathering programs.

- Instrument Engineer--Two engineers are estimated for system operation, maintenance, and modification during the five-year program.

- Meteorologist--Two meteorologists are estimated to be required to provide sustained analysis of meteorological conditions in the St. Louis area and direct support to field groups for specific purposes.

- Computer System Engineer--One engineer is estimated to be required for supervision of data handling and recording procedures, special computer program preparation, and related duties.

- Control Engineer--The control engineer will be responsible for development and maintenance of the St. Louis emission inventory.

- Effects Research--An on-site professional is estimated to be required to provide direct support for all effects research in the St. Louis area; he will arrange for acquisition of all pertinent local data necessary for the program.

VIII COST SUMMARY

Permanent Facilities and Staff

Initial costs of the St. Louis facility have been estimated at about $3.94 million. This includes all instrument stations, the central facility, and other equipment estimated to be required. These initial costs are summarized in Table 2.

Table 2

ESTIMATED INITIAL COSTS OF THE ST. LOUIS
FACILITY BY PRINCIPAL INSTALLATION
(Thousands of Dollars)

Instrument Stations	
A_1	$ 771.3
A_2	625.6
B_1	1,370.4
B_2	455.2
C_1	134.0
C_2	367.2
Subtotal	$3,723.7
Central facility	121.0
Vehicles	98.9
Total	$3,913.6

The estimated initial costs can also be summarized in terms of the principal system components as shown in Table 3.

Table 3

ESTIMATED INITIAL COSTS OF THE ST. LOUIS
FACILITY BY SYSTEM COMPONENTS
(Thousands of Dollars)

	Cost
Air quality instruments	$1,606.0
Calibration equipment and accessories	392.2
Meteorological instruments	234.2
Instrument spare parts	220.5
Site preparation, housing, fixtures	501.5
Digital data terminal equipment	769.2
Data processing and communication	81.0
General facilities	40.0
Support vehicles	98.9
Total	$3,943.6

The air quality instruments account for almost one-half the initial costs at $1.6 million, with the digital data terminals at somewhat less than 18% of the total. One of the lowest cost elements is attributable to the data processing and communication facilities and accounts for slightly more than 2% of the total costs. Significant advances in the state of the art and high volume production of computers and peripheral equipment have combined to create dramatic reductions in cost over the past two to three years.

The annual operating cost once full operational status has been achieved is estimated at about $1.5 million. This cost includes the staff at both Research Triangle Park and St. Louis and all standard operating supplies at St. Louis. These costs are summarized in Table 4.

The estimated personnel costs clearly constitute the chief element of the annual costs, accounting for almost 80% of the total. The remaining elements stand at 6% or less. A particularly uncertain cost is that for rental of the central facility and especially land for the instrument stations. A cost for instrument station sites was taken nominally at $1000 per site. Undoubtedly, large variations will be found in this unit estimate which can only be known with certainty following the actual field survey.

Table 4

ESTIMATED TOTAL ANNUAL OPERATING COSTS OF THE ST. LOUIS FACILITY AND PERMANENT STAFF

(Thousands of Dollars)

Personnel	
Research Triangle Park	$ 225.0
St. Louis	990.0
Subtotal	$1,215.0
Instrument replacement and parts	91.8
Motor vehicle operation	14.5
Telephone communication system	38.4
Building and land rental	78.4
Calibration gases	98.0
Electric power	12.7
Total	$1,548.8

The activation schedule of the St. Louis facility is estimated to span about five calendar quarters following authorization of the Regional Study. The overall expenditure schedule for both the initial and operating costs by quarter is summarized in Table 5. The operating costs in the fifth quarter are judged to typify all subsequent quarters.

Table 5

ESTIMATED INITIAL AND OPERATING COSTS DURING IMPLEMENTATION OF THE ST. LOUIS FACILITY

(Thousands of Dollars)

	Quarter				
	1	2	3	4	5
Initial costs	$ 48.8	$317.1	$2,770.2	$470.9	$306.6
Operating costs	99.1	163.3	288.7	349.0	387.2
Total	$147.9	$510.4	$3,058.9	$819.9	$693.8

Helicopter and Mixing Layer Observational Program

The estimated costs of the mixing layer observational program are presented in detail in Chapter XIV of Part III. The costs cover the acquisition and operation of one helicopter and a balloon-borne instrument system known as METRAC. Operational costs of the helicopter are based on 18 hours of operation during the period March through November and 12 hours per week for the balance of the year. Total helicopter costs on a quarterly basis for this operational schedule are shown in Table 6.

Table 6

ESTIMATED COSTS OF HELICOPTER
OPERATION BY QUARTER
(Thousands of Dollars)

Quarter	Cost
January-March	$19.3
April-June	24.1
July-September	24.1
October-December	16.9
Total	$84.4

Research Plan

The following sections present the estimated requirements for personnel, major equipment, and the costs of these programs. Although these estimates are judged to be suitable for the planning purposes of this Prospectus, they will require continual review and modification in further planning of the Regional Study and during its execution. This is especially important for the estimates in the later time periods. The estimates are intended to cover the requirements of each particular program component, and all are considered a part of the Regional Study. Further consideration of the Research Plan and perhaps the EPA policy considerations may result in the transfer of part or all of certain program components from the Regional Study to other components of the ongoing EPA research program.

The estimated costs of the Research Plan as presented in Chapter XXI of Part IV total $9.7 million and are summarized later in Table 11. By far the bulk of the costs are attributable to personnel, accounting for 85% of the total. About $900,000 is estimated to be required for specialized instruments for selected components of the Research Plan. Because of their somewhat specialized nature or because they require additional development to achieve operational status they were not considered as part of the permanent facility.

Personnel

Requirements

Requirements estimated for personnel stemming from the Research Plan are summarized in Table 7. Scheduling is shown on the assumption that the Regional Study is authorized by July 1, 1972. More than 311 man-years of professional and technical support personnel are estimated to be required to carry out the Research Plan. Almost one-half the personnel requirements stem from the 100-series tasks--Model Verification--alone. Within this series about one-half of the personnel are associated with the critical 104 component which covers the specific efforts associated with model verification. The 100 and 200 series have a ratio in the range of two-thirds to three-fourths between professional and technical support personnel which tends to be appropriate in view of the extensive laboratory and field efforts expected. The 300 to 400 series tend to require considerably fewer technical support personnel compared with the number of professionals, because far lower field efforts are expected.

Table 7

SUMMARY OF PERSONNEL REQUIREMENTS FOR THE RESEARCH PLAN
(Man-Years)

Program Element	Professional	Support	Clerical	Total
100	83	118	14	215
200	25	40	4	69
300	9	9	2	20
400	16	5	3	24
Total	133	172	23	328

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300	9	9	2	20
400	16	5	3	24
Total	133	172	23	328

Each of the four major program elements is expected to be coordinated by the various Research Division representatives in the Office of Research Operations. Major program components, especially those continuing throughout the life of the Regional Study, would necessarily have full-time supervisors within the respective interested Research Divisions. The extent to which contractor participation will be necessary and appropriate is difficult to state and would likely depend on the balance between program requirements in terms of scheduling and capability and the available resources within EPA. Total personnel requirements, however, should remain substantially identical regardless of the manner in which the effort is conducted.

Professional and technical support personnel were estimated on a task-by-task basis from their descriptions in Part II. An additional component of the staffing would include clerical support. For planning purposes, clerical personnel requirements are estimated on the basis of one per six professionals, bringing the total requirements to 328 man-years.

Costs

The total estimated costs of personnel associated directly with the tasks included in the Research Plan are presented in Table 8, based on the requirements shown in Table 7. The estimated costs, as discussed in Chapter XIX of Part IV are based on a unit cost of $25,000 per year per staff member, regardless of his labor or job classification. With the mix of classifications estimated to be required, the aggregated estimates should be valid. Estimates for the smaller components of the Research Plan that do not have a balanced staffing pattern would tend to be less reliable. The unit cost includes direct salary, benefits, travel, and all other funds necessary for support.

Total personnel costs directly associated with the Research Plan are estimated at about $8.3 million.

Table 8

ESTIMATED COST OF PERSONNEL REQUIRED BY THE RESEARCH PLAN
(Thousands of Dollars)

Calendar Year	100	200	300	400	Total
1972	$ 383.6	$ 24.9	--	--	$ 408.5
1973	1,112.7	87.3	$208.4	$105.0	1,413.4
1974	1,202.0	445.0	108.4	180.3	1,935.7
1975	1,128.5	490.5	108.4	149.9	1,877.3
1976	1,035.2	525.6	108.4	156.3	1,825.5
1977	507.1	157.1	51.2	154.7	873.4
Total	$5,369.1	$1,730.7	$487.8	$746.2	$8,333.8

Instrumentation and Equipment

The bulk of the instrumentation and equipment necessary for execution of the Research Plan is included in the St. Louis facility as discussed in Chapters XI-XII of Part III and Chapter XVIII of Part IV. These items are generally expected to function throughout the life of the Regional Study. However, several major items of equipment are included more appropriately in the costs of the Research Plan rather than in the St. Louis facility. The first includes the METRAC balloon-borne instrument system discussed in Chapter III of Part II and Chapter XIV of Part III for observations in the mixing layer.

Costs for additional research and development were estimated at $100,000 in the first year after authorization of the Regional Study. If the development is successful, an additional cost of $376,000 was estimated for full implementation of the system having a capability to simultaneously track six balloons. The estimated costs by quarter are shown in Table 9. Program element 200--Atmospheric Chemical and Biological Processes--is estimated to require certain additional instrumentation and equipment not included in the St. Louis facility. Their costs are included within the costs of the Research Plan rather than the St. Louis facility. Table 9 presents the estimated costs of these instruments and equipment by program component and date of acquisition. Compared with personnel costs, these expenditures tend to be modest except perhaps for the gas chromatograph-mass spectrometer estimated at $100,000.

Table 9

ESTIMATED COSTS OF SPECIALIZED EQUIPMENT FOR THE RESEARCH PLAN
(Thousands of Dollars)

Program Component	Equipment Description	Quantity	Cost	Acquisition Date Year/Quarter
103	METRAC system development	-	$100.0	1972/4
	METRAC procurement and installation		376.0	1974/1
201	Gas chromatograph	3	18.0	1975/1
	Electron capture gas chromatograph	3	14.0	1975/1
	G. C. mass spectrometer	1	100.0	1975/1
	Correlation spectrometer	1	10.0	1975/1
	Recorders for gas chromatographs	6	6.0	1975/1
	Sample vessels, valving, standard units	--	10.0	1975/1
	Total		$158.0	
202	Electron mobility counter	2	10.4	1974/1
	Royco photometer counter	5	11.3	1974/1
	Anderson impactor	5	5.6	1974/1
	Total		$ 87.3	
203	Atomic absorber	1	1.0	1975/1
	Transmissometer	3	27.0	1975/1
	Radiative balance instruments		50.0	1973/3
	Total		$ 81.0	
204	Digital pH meter	5	5.0	1974/2
	Tipping bucket rain-gage	10	3.2	1974/2
	Fabrication of precipitation pH measurement and calibration	5	2.5	1974/2
	pH meter	1	1.8	1974/2
	Chemical electrodes	7	1.4	1974/2
	Total		$ 13.9	
406	Thermosonde	3	120.0	1973/2
	Acoustic sounder	2	40.0	1973/2
	Total		$160.0	

This unit would be installed at the central facility with the bulk of the remaining items installed mainly at selected Class A and B stations as discussed in the Research Plan.

Finally the research effort under program element 402--Atmospheric Modeling--will require the use of two atmospheric sounders and three thermosondes early in 1973. The estimated costs of these units are also presented in Table 9.

Operations

Execution of the Research Plan will entail certain direct operating costs in both the 100 and 200 series. In the 100 series, significant costs are estimated to be associated with the 101 component for the operation of the METRAC system during wind transport and tracer studies. The Research Plan indicates the execution of the wind-tracking experiment during the second and third quarters of 1974 and tracer studies in the same quarters in 1975.

As noted in Chapter XIV of Part III the estimated operating costs of the METRAC system are $8000 per month per balloon launch point for an intensive experimental effort. Thus, if the METRAC system is taken as having four launch points, the total operating costs would be $32,000 per month. Under the research schedule shown above, the quarterly METRAC operational costs expected are shown in Table 10.

Table 10

ESTIMATED OPERATIONAL COSTS
OF THE METRAC SYSTEM
(Thousands of Dollars)

Year--Quarter	Cost
1974--2	$ 92
1974--3	92
1975--2	92
1975--3	92
Total	$368

Operating costs of the efforts in the 200 series are expected to cover consumable and expendable laboratory supplies and equipment. The costs of these items should be insignificant in comparisor to personnel costs, for example, so that a detailed estimate here does not appear warranted. Accordingly, an average cost of $4000 per quarter will be taken as the cost of these consumable and expendable items.

Total Cost of Research Plan

The total estimated cost of the effort covered by the Research Plan is summarized in Table 11 by quarter. A total of $9.7 million is estimated, with about 85% attributed to personnel. On an annual basis, costs tend to peak in 1974 at $2.6 million, caused primarily by higher costs of equipment acquisition and operations.

Total Costs of RAPS

The total estimated cost of the Regional Study is summarized in Table 12 by quarter and is almost $21.2 million. The schedule is based on the assumption that the Regional Study would be authorized on July 1, 1972, and that activities are initiated immediately. The greatest part of the total costs are attributable to personnel, with about two-thirds of the total costs. Except for the quarter in which the St. Louis facility is largely completed, the cost within any category does not exceed personnel costs. The research staff costs tend to lie in the range of 1.5 times the permanent staff. Combined instrument costs of the St. Louis facility and the Research Plan are close to $5.0 million, or almost 25% of the total estimated cost.

Table 11

TOTAL ESTIMATED COSTS OF THE RESEARCH PLAN
(Thousands of Dollars)

Year-Quarter	Personnel	Instruments	Operations	Total
1972-3	$ 175.6		$ 4.0	$ 179.6
-4	232.9	$100.0	4.0	336.9
Subtotal	$ 408.5	$100.0	$ 8.0	$ 516.5
1973-1	304.2		4.0	308.2
-2	338.9	160.0	4.0	502.9
-3	395.9	50.0	4.0	449.9
-4	374.4		4.0	378.4
Subtotal	$1,413.4	$210.0	$ 16.0	$1,639.4
1974-1	480.1	463.3	4.0	947.4
-2	504.5	13.9	96.0	614.4
-3	476.9		96.0	572.9
-4	474.2		4.0	478.2
Subtotal	$1,935.7	$477.2	$200.0	$2,612.9
1975-1	479.1	189.0	4.0	672.1
-2	470.8		96.0	566.8
-3	467.7		96.0	563.7
-4	459.7		4.0	463.7
Subtotal	$1,877.3	$189.0	$200.0	$2,266.3
1976-1	465.7		4.0	469.7
-2	444.2		4.0	448.2
-3	448.6		4.0	452.6
-4	467.0		4.0	471.0
Subtotal	$1,825.5		$ 16.0	$1,841.5
1977-1	442.9		4.0	446.9
-2	430.5		4.0	434.5
Subtotal	$ 873.4		$ 8.0	$ 881.4
Total	$8,333.8	$976.2	$448.0	$9,758.0

Table 12

ESTIMATED TOTAL QUARTERLY COSTS OF THE REGIONAL STUDY
(Thousands of Dollars)

	Initial Costs		Operating Costs					
			Equipment			Personnel		
Year-Quarter	St. Louis Facility	Research Instruments	Helicopter	St. Louis Facility	Research Plan	Permanent Staff	Research Staff	Total
1972-3	$ 48.8			$ 2.0	$ 4.0	$ 97.0	$ 175.6	$ 327.4
-4	347.1	$100.0	$ 16.9	12.1	4.0	151.2	232.9	864.2
Subtotal	$ 395.9	$100.0	$ 16.9	$ 14.1	$ 8.0	$ 248.2	$ 408.5	$ 1,191.6
1973-1	2,770.2	160.0	19.3	51.0	4.0	237.7	304.2	3,546.4
-2	470.9	50.0	24.1	57.0	4.0	292.0	338.9	1,236.9
-3	306.6		24.1	83.5	4.0	303.7	395.9	1,117.8
-4			16.9	83.5	4.0	303.7	374.1	782.5
Subtotal	$3,547.7	$210.0	$ 84.4	$ 275.0	$ 16.0	$1,137.1	$1,413.1	$ 6,683.6
1974-1		463.1	19.3	83.5	4.0	303.7	480.1	1,353.7
-2		13.9	24.1	83.5	96.0	303.7	504.5	1,025.7
-3			24.1	83.5	96.0	303.7	476.9	984.2
-4			16.9	83.5	4.0	303.7	474.2	882.3
Subtotal		$477.0	$ 84.4	$ 334.0	$200.0	$1,214.8	$1,935.7	$ 4,215.9
1975-1		189.0	19.3	83.5	4.0	303.7	479.1	1,078.6
-2			24.1	83.5	96.0	303.7	470.8	978.1
-3			24.1	83.5	96.0	303.7	467.7	975.0
-4			16.9	83.5	4.0	303.7	459.7	867.8
Subtotal		$189.0	$ 84.4	$ 334.0	$200.0	$1,214.8	$1,877.3	$ 3,899.5
1976-1			19.3	83.5	4.0	303.7	465.7	876.2
-2			24.1	83.5	4.0	303.7	444.2	859.5
-3			24.1	83.5	4.0	303.7	448.6	863.9
-4			16.9	83.5	4.0	303.7	467.0	875.1
Subtotal			$ 84.4	$ 334.0	$ 16.0	$1,214.8	$1,825.5	$ 3,471.7
1977-1			19.3	83.5	4.0	303.7	442.9	853.4
-2			24.1	83.5	4.0	303.7	430.5	845.8
Subtotal			$ 43.4	$ 167.0	$ 8.0	$ 607.4	$ 873.4	$ 1,699.2
Total	$3,943.6	$976.0	$397.9	$1,458.1	$448.0	$5,637.1	$8,333.8	$21,194.5

DRAFT

Environmental Protection Agency
National Environmental Research Center
Research Traingle Park, North Carolina 27711

REGIONAL AIR POLLUTION STUDY

for St. Louis, Missouri

RAPS Series

No. I. Study Plan

August 1972
(Revised April 1973)

DRAFT

REGIONAL AIR POLLUTION STUDY
for St. Louis Missouri

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ACKNOWLEDGMENT

This report is a summary outline of the plan of research and field facilities for the initial phase of the Environmental Protection Agency (EPA) regional air pollution studies program. A preliminary study design of such a program was prepared for EPA by the Stanford Research Institute (SRI) under Contract 68-02-0207 and was reported in their Regional Air Pollution Study: A Prospectus (4 vols.). While the SRI study is being used as a model for the EPA study, it has been necessary to depart significantly from it in many of the details of the research and the facility. Authors of this EPA plan have referred to the SRI Prospectus here and there and readers will find the Prospectus a valuable resource for ideas and philosophy on regional studies.

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NOTICE

This document is a preliminary draft. It has not been formally released by EPA and should not at this stage be construed to represent Agency policy. It is being circulated for comment on its technical accuracy and policy implications.

1. INTRODUCTION

BACKGROUND

The need for the development of an adequate scientific basis for air quality management and improvement has been long recognized. The "Clean Air Act Amendments of 1970" require the establishment of national primary and secondary ambient air quality standards and the design of implementation plans to meet those standards. Whereas the matter was previously largely academic, the 1970 Amendments have focused attention on the basis of, and rationale for, those management tools and concepts available for the formulation of the necessary abatement plans or strategies.

The 1970 Amendments clearly presuppose that "performance" (i.e., emission) standards can be set with respect to achievement of air quality standards through either an appreciation of those physical and chemical factors of transport, dispersion, and transformation within the atmosphere that govern source-receptor relationships being built into the control strategy or (2) an accommodation such as "universal abatement" in which all sources of a pollutant are reduced to the maximum extent possible within the state of the art, or to a level (linearly) proportional to the degree of air quality improvement needed to meet standards.

In practice, universal abatement strategies can be formulated more readily than strategies that take into account source-receptor relationships through simulation modeling of the atmospheric processes. The universal abatement concept offer little more than a hope achieving the desired effect on air quality on all significant scales of time and space. Further, the concept is an arbitrary one in that consideration is given neither to the fact that all sources do not contribute to an air pollution problem in proportion to the strength of their emissions nor to the cost-benefit factors that should be taken into account in a responsible air quality management scheme.

In principle, the deficiencies of the universal abatement concept can be overcome through utilization of simulation modeling techniques in the development of abatement strategies. This means information can be developed on the costs of control for each source or set of sources for different kinds of abatement practices and for different levels of control. It is possible to identify least-cost solutions for existing and possible new air quality standards, and to clarify or delineate the cost-benefit relationships. It is recognized, however, that much improvement is needed in the scientific and technical knowledge and capability necessary to relate confidently, in an analytical fashion, the cause and effect both between emission and air quality and between control strategies and air quality.

There can be no doubt as to the value of such a capability for testing strategies. Without it, intelligent direction cannot be given to improving the state of the art of emission control, nor can correct decisions be made between alternatives on (1) control strategies that do not depend on suppression of emissions, or (2) allocation of priorities for selective source control. In either case, the assessment of cost-effectiveness is decidedly limited without the capability.

OBJECTIVES OF RAPS

The overall objective of the Regional Air Pollution Study (RAPS) is to develop mathematical simulation models of air pollution processes. The models will be quantitative formulations of all the atmospheric processes of pollutants, including (1) dissipation of pollutants through diffusion, advection, and other similar processes, (2) transformation of pollutants by chemical reactions, and (3) removal of pollutants. With this mathematical tool, the results of pollutant control actions and strategies can be predicted. If the models are accurate and the data input correctly known or forecast, the output of the models will show the effects of changes within the region, whether these effects are a result of controls or are inadvertent. The accuracy of the models will depend on the degree to which the atmospheric processes are understood and described by the mathematical techniques.

Although the objective of the study can be stated in a few words, the problems to be encountered in pursuing the objective appear to be exceedingly complex and wide ranging. The study will require investigations in meteorology, atmospheric chemistry, aerosol physics, applied mathematics, and other disciplines. Some of the steps in the investigation are:

1. Evaluate the capability of mathematical simulation models to describe the transport, diffusion, and concentration of both inert and reactive pollutants over a regional area.
2. Develop a more complete understanding of the atmospheric motions over an urban region, both those imposed by the presence of urban structures, heat sources, and pollution and those naturally

present in the atmosphere on an urban scale that influence the concentrations of pollutants.

3. Develop a more complete understanding of the system of chemical transformations, gas-particle interactions, and photochemical processes that take place in the urban atmosphere.
4. Determine the correct rate constants for use in the systems of chemical rate equations for different ambient atmospheric conditions.
5. Test the evolution of the models in both laboratory and field experiments.
6. Evaluate significant factors in the design of improved control strategies in the urban/rural complex, including economic costs and the roles of land use and community planning.

An important outgrowth of RAPS will be the development of an improved technology that can be applied in local and regional control operations. Most noteworthy will be the techniques that must be developed in order to adequately describe the emission inventories of both stationary and mobile sources. The study is also expected to push forward the state of the art in air quality and meteorological monitoring, data handling, and data analysis.

The application of air quality models is still in the early evolutionary stages. A wide diversity of models exist or are being developed, ranging from those used on quite limited problems--such as diffusion from a single point source--to models that can be applied to the extended scale covering large urban complexes. Only in a few simple cases are the models sufficiently tried and verified to warrant confidence in their use.

One of the major reasons for the lack of adequate mathematical models for air pollution processes is simply that the problem has not been attacked on an adequate scale. With the limited funds and resources available to date, progress has lagged far behind the need. The development and verification of suitable models are very difficult activities, especially on the major urban scale, and depend strongly on the availability of adequate data on which to base the formulation and to develop its application. It is possibly even more difficult to assess the capability of the model and to measure its precision accurately, especially where long time periods are needed to provide an adequate basis of comparison.

The steps to be taken in conceiving, developing, and proving an air quality model are shown diagramatically in Figure 1. To the present, most progress has been made in understanding the processes and in formulating the model, even though the observation of the various conditions involved has been quite inadequate. Operation of the model both for description and prediction purposes has generally been constrained, and the evaluation of the results against observations has frequently been inconclusive.

A decisive limitation in the process lies in the first area noted in the diagram, Observation of Various Conditions. This step is fundamental to all aspects of the problem, and shortcomings here cripple every subsequent endeavor. Thus, many existing models are based on the very limited data that have been acquired routinely for quite different purposes, e.g., airway weather observations, and are woefully inadequate in both extent and spatial and temporal resolution for the development and verificati of models.

The limitation of basic data results from the high cost of collecting such data on sufficiently continuous and extensive scales in space and time. When attempts have been made to set up special networks of observational facilities and carry out intensive data collection programs, the results have often left much to be desired and have reflected the shortcuts that have been taken because of costs in acquiring the necessary instrumentation and in collecting and handling the data.

Even with the emergence of moderately priced automatic data processing facilities, the acquisition of basic data remains a considerable and costly undertaking. But to those considering the problems of air quality management, it has become increasingly clear that little progress can be made in the solution of such problems unless they are treated on a major and extended scale.

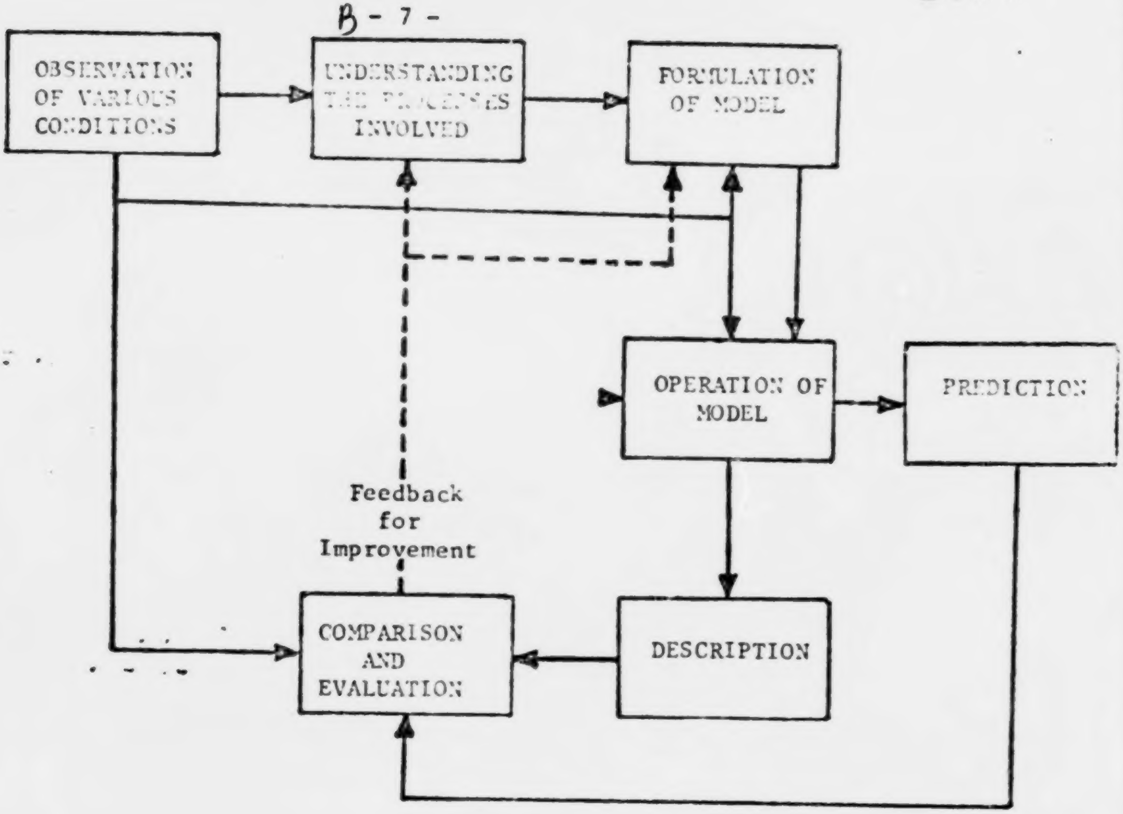
OBSERVATION OF VARIOUS CONDITIONS
UNDERSTANDING THE PROCESSES INVOLVED
FORMULATION OF MODEL
OPERATION OF MODEL
PREDICTION
Feedback for Improvement
COMPARISON AND EVALUATION
DESCRIPTION

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Figure 1. Steps in Developing the Air Quality Model

The difficulties of air quality management are apparent in the concept of Air Quality Control Regions, where emission within the region are to be related to air quality standards. In relating emissions to these standards, it is necessary that all levels of activity, from local to extended regional concerns, there be an adequate understanding of how emission from the several sources combine and react to produce concentrations of specific pollutants through the area. This is particularly true where the air quality of large rural and suburban areas is greatly affected by emissions from remote urban centers that may be up to 100 miles away. Control and abatement procedures must take these indirect effects into account. To formulate economical and realistic strategies for the development of such procedures, however, it is necessary also to consider the less direct aspects of health, economics, land use, and community planning in the urban/rural complex.

In the application of simulation models to decisions on control strategies, it is vitally important to ensure that all concerned have confidence in the approach. There are large financial involvements; the livelihood of whole communities may be at stake and there may be tremendous pressures on limited resources to plan, implement, and enforce control strategies. Sound modeling capability, with demonstrated accurate results, would serve all aspects of these interests and would provide the basis on which sound enforcement strategies could be sustained.

It should be noted that the overall purpose of RAPS is to provide the basis for the formulation of control strategies rather than to develop control and abatement procedures as such. Its relationship to the analytical and decision-making processes in formulating control strategies is illustrated diagramatically in Figure 2.

The RAPS plan is based on the assumption that RAPS will be an independent, self-sufficient activity of the Environmental Protection Agency (EPA). Although some economy and improvement might result from integrating the resources and research efforts in RAPS with those of other programs planned for the St. Louis area, it is considered that the scope and importance of the RAPS program require that it be carried out as a principal endeavor. Any proposal to share resources between programs will be carefully evaluated to ensure that efforts are not deflected from the main goals of RAPS or of the other programs.

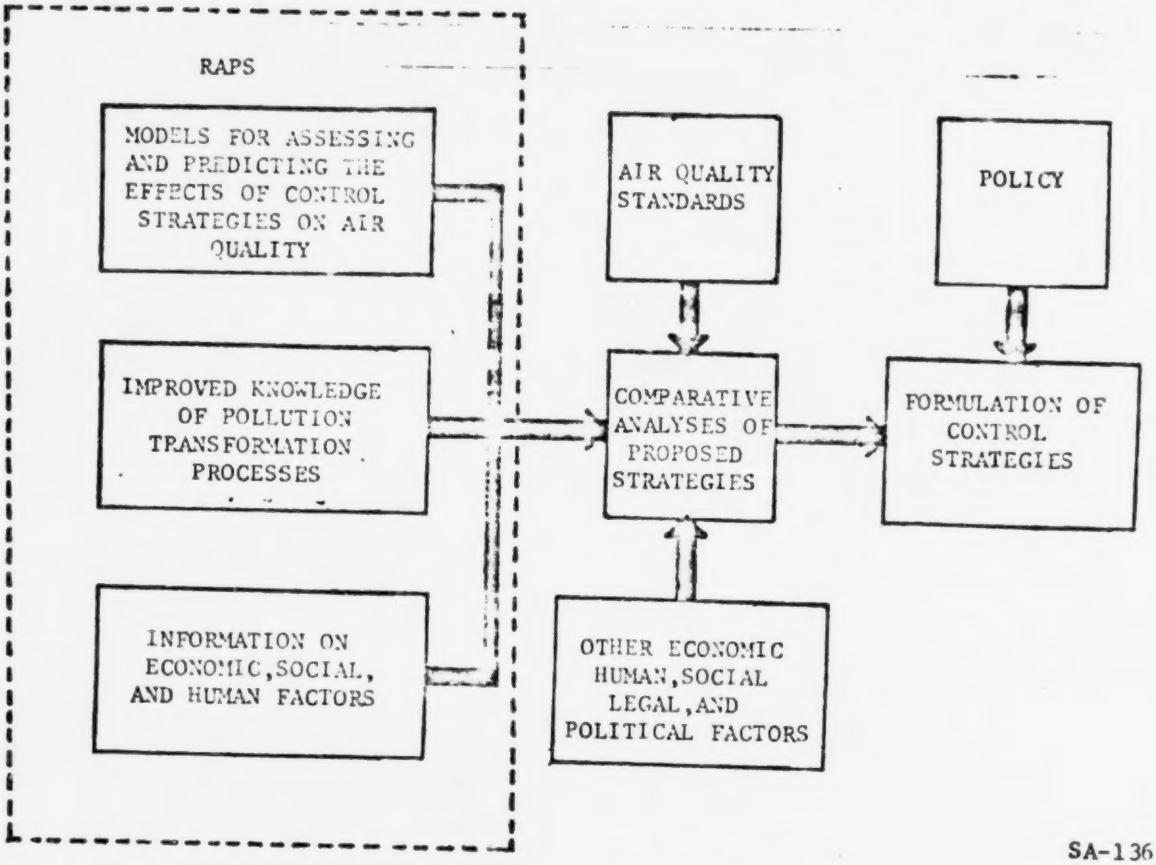
RAPS
MODELS FOR ASSESSING AND PREDICTING THE EFFECTS OF CONTROL STRATEGIES ON AIR QUALITY
IMPROVED KNOWLEDGE OF POLLUTION TRANSFORMATION PROCESSES
INFORMATION ON ECONOMIC, SOCIAL, AND HUMAN FACTORS
AIR QUALITY STANDARDS
COMPARATIVE ANALYSES OF PROPOSED STRATEGIES
OTHER ECONOMIC HUMAN, SOCIAL LEGAL, AND POLITICAL FACTORS
POLICY
FORMULATION OF CONTROL STRATEGIES

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Figure 2. Regional Air Pollution Study Role in the Overall EPA Function of Formulating Control Strategies

SELECTION OF STUDY AREA

Thirty-three Standard Metropolitan Statistical Areas larger than 400,000 polulation were evaluated by the Stanford Research Institute (SRI), with regard to:

1. Surrounding area: Isolation from other large areas containing sources of considerable air pollution, presence of a clear-cut gradient of emissions around the edge of the urban area, and absence of large bodies of water.
2. Heterogeneous emissions: Presence of a satisfactory mixture of emissions and types of sources within the area.
3. Area size: An indication of the scope and magnitude of the study for each site.
4. Pollution control program: Existence of a well developed control program as a source of background data, experience, and industrial cooperation.
5. Historical information: Adequate meteorological, air quality, economic, and other forms of information for the study.
6. Climate: Relatively uncomplicated meteorological patterns and a climate that is suitable for year-around outside work.

The SRI recommendation that St. Louis be selected as the study site has been accepted and approved by EPA.

2. THE FACILITY

RATIONALE

Basic Operations

The RAPS program requires two types of field operations: (1) the research expedition, characterized by a limited or single objective and by relatively short periods of field operation for data acquisition, and (2) routine data acquisition over an extended period of time for ongoing model research. The basic RAPS task areas (described in Chapter 4) include projects in both field operational categories; however, since the provision of a data acquisition network for the second category represents a major investment of both funds and personnel, the needs for such an investment will be carefully examined.

Basis for Monitoring Network

A major objective of the RAPS program is the verification and evaluation of simulation modeling techniques. To fulfill the RAPS goals, this verification process must include much more than a statistical comparison of observed and model-predicted pollutant concentrations in the area around a source region. The RAPS program must also enable separate evaluation of the several submodel routines that are component parts of all simulation modeling systems. The comparison of the submodel routines (e.g., the transport wind direction field) with the actual conditions prevailing during the verification test operation will permit the identification of specific weaknesses in the simulation programs and procedures. Follow-up research leading to modifications in the simulation procedures can then be conducted to improve and extend the candidate simulation techniques.

Since the objective of the RAPS program is the verification of a variety of current and future candidate model systems, the verification data acquisition system should be geared specifically to the range of verification problems that the RAPS program is expected to solve. Thus the RAPS verification data acquisition system must (1) include detailed meteorological and air quality measurements, (2) give simultaneous source data over adequate distances and (3) provide these data on ambient conditions for periods at least as short as 1 hour and as long as 1 year. In this context, detailed air quality data include ambient air concentration information for pollutants that are covered by current and proposed air quality criteria, including but not limited to sulfur dioxide, carbon monoxide, nitric oxide, nitrogen dioxide (SO_2, CO, NO, NO_2), oxidants, hydrocarbons, and suspended particles, because model verification studies are expected to be concerned with these individual pollutants.

The RAPS program also is directed toward providing new data and an improved understanding of atmospheric chemical reactions, pollutant scavenging, and other atmospheric processes.To achieve this goal requires, as a foundation, detailed data on atmospheric pollutant concentrations that a monitoring system can provide most effectively. The needs of this program are generally parallel to the basic components required for the model verification program. The planned monitoring system incorporates some components and design features that are specifically directed toward supporting chemical transformation studies and scavenging projects.

The RAPS program is also specifically charged with the responsibility of improving technology to meet the needs of simulation modeling. This effort is most necessary in connection with air monitoring networks, including the development of optimum designs, improved operational procedures, and automatic data processing techniques.

The RAPS program requires a sophisticated air monitoring network. Because of the area to be covered, the number of variables that are to be monitored, and the requirement for simultaneous measurements across the region, a computer-controlled telemetering network is being designed. Instrumentation components in most cases, are the newer designs now being specified for local and regional use, although they have not generally been placed into routine service by local control agencies.

To ensure that adequate data are available for investigations that cannot be defined a priori, it will be necessary to make extensive and continuous collections that will include some material that may be used quite infrequently; their importance in achieving the program objectives may nontheless be great. This principle is well recognized and accepted in many observational activities - especially where weather is involved. With modern data acquisition processing systems, however, the unit cost of collecting additional data decreases rapidly after the initial investment in obtaining and installing equipment and in setting up procedures. Indeed, if data are to be collected at successive times throughout the year (even if considerable intervals between collection periods can be anticipated), it is almost certain that little or no savings in overall costs could be made by operating intermittently, since the expense of shutting down and starting up would outweigh any minor advantages from not running continuously on a routine basis.

THE ST. LOUIS RAPS FACILITY

The St. Louis RAPS facility is to be the data acquisition base for the regional study. It will include the Regional Air Monitoring System (RAMS) of air quality and meteorological instrument stations established within an area roughly enclosed by a circle with its center at the Gateway Arch and a radius of 30 kilometers (km.). A central support facility will be provided for automatic and manual data handling and processing, and this facility may also contain most offices and laboratory space as well as instrument maintenance and repair shops. The RAMS stations are expected to be linked to the central facility by telephone circuits for automated data recording. Other components of the St. Louis facility will include mobile monitoring stations and laboratories, atmospheric sounding stations, helicopter and aircraft instrument platforms, and equipment for miscellaneous other measurement capabilities.

THE REGIONAL AIR MONITORING SYSTEM

The RAMS is planned as the basic data source for the RAPS. In accordance with the research plan described in Chapter 4, it will be operated with the primary purpose of producing a comprehensive data base relative to air quality and meteorological conditions; by use of this data, mathematical models that accurately describe air pollution transport and transformation processes will be developed and validated. Detailed statistical analyses and other types of studies will be conducted as required by the various elements responsible for implementing the research plan.

During the field studies and data-acquisition efforts covered in the research plan, RAMS will be operated to support these activities most effectively. Support will include equipping the instrument stations with additional or experimental instruments, locating transportable stations as specified by the research groups, preparing and operating specialized data processing programs, and providing other instrument and experimental technician support. Air quality data will be used as partial input for studies of atmospheric chemistry. Meteorological measurements are included in the basic network, to be used both as direct input in model development and as input for research into the physical aspects of the urban boundary layer structure.

Network Criteria -- Sampling station areal density should be roughly proportional to the gradients of long-term mean concentrations (seasonal or annual). In addition, an attempt should be made to provide a reasonably complete set of source-receptorrelationships with the network. Previous studies furnish some information on patterns of SO_2 and suspended particulate concentrations; these indicate the main spatial variations are limited to an area centered in downtown St. Louis, with a radius of about 15 km. More limited information is available concerning the distribution of automotive pollutants. For the primary pollutants, modeling studies indicate that spatial variations of concentrations are highly correlated with spatial variations of emissions, and thus, in a restricted sense, to urbanization. Concentrations of secondary pollutants are expected to show much less fine-scale variability, with the distribution being a broad plume having a width about that of the urban area and extending downwind. On the basis of the criteria and inference concerning the distribution of pollutants, the highest station density should be centered over the downtown area, with station density decreasing with distance.

Siting criteria for meteorological measurements differ somewhat from air quality siting criteria, but since the station density for air quality measurements appears adequate for meteorological measurements, the latter data can be obtained at selected sites.

The Proposed Network -- The network shown in figure 3 is in accordance with the above criteria and with available funding. It consists of a central station, located in the vicinity of the Gateway Arch, with four concentric rings of six stations each (indicated by X's in the figure) at a distance of 4, 8, 15, and 30 km from the central site. At each of these 25 stations, the following pollutant and meteorological parameters will be measured: carbon monoxide-methane-hydrocarbons, hydrogen sulfide-sulfur dioxide, ozone, nitrous oxide-oxides of nitrogen, fine particulated, wind speed and direction, ambient temperature, and dew point temperature.

Additional sampling sites may be chosen in the northeast sector to sample in the area of the expected maximum impact of the large sources on the Illinois side of the river when winds are from the southern sector; these stations are indicated by circles, but the best array will be determined from a more specific survey of the locations of the major point sources. The pollutants to be sampled at these locations are dependent on what the sources emit. One or two additional sites in the southwest quadrant (indicated by the single circle on the figure) may be desirable to adequately sample the build-up of automotive pollutants across the rural-suburban-urban fetch with southwest winds.

The supplementary meteorological measurements to be made at the various sites are indicated by the letters in Figure 3. At three distant sites and one urban site, comprehensive solar and sky radiation measurements (R) are to be made. These will be supplemented by pyranometer measurements (r) at

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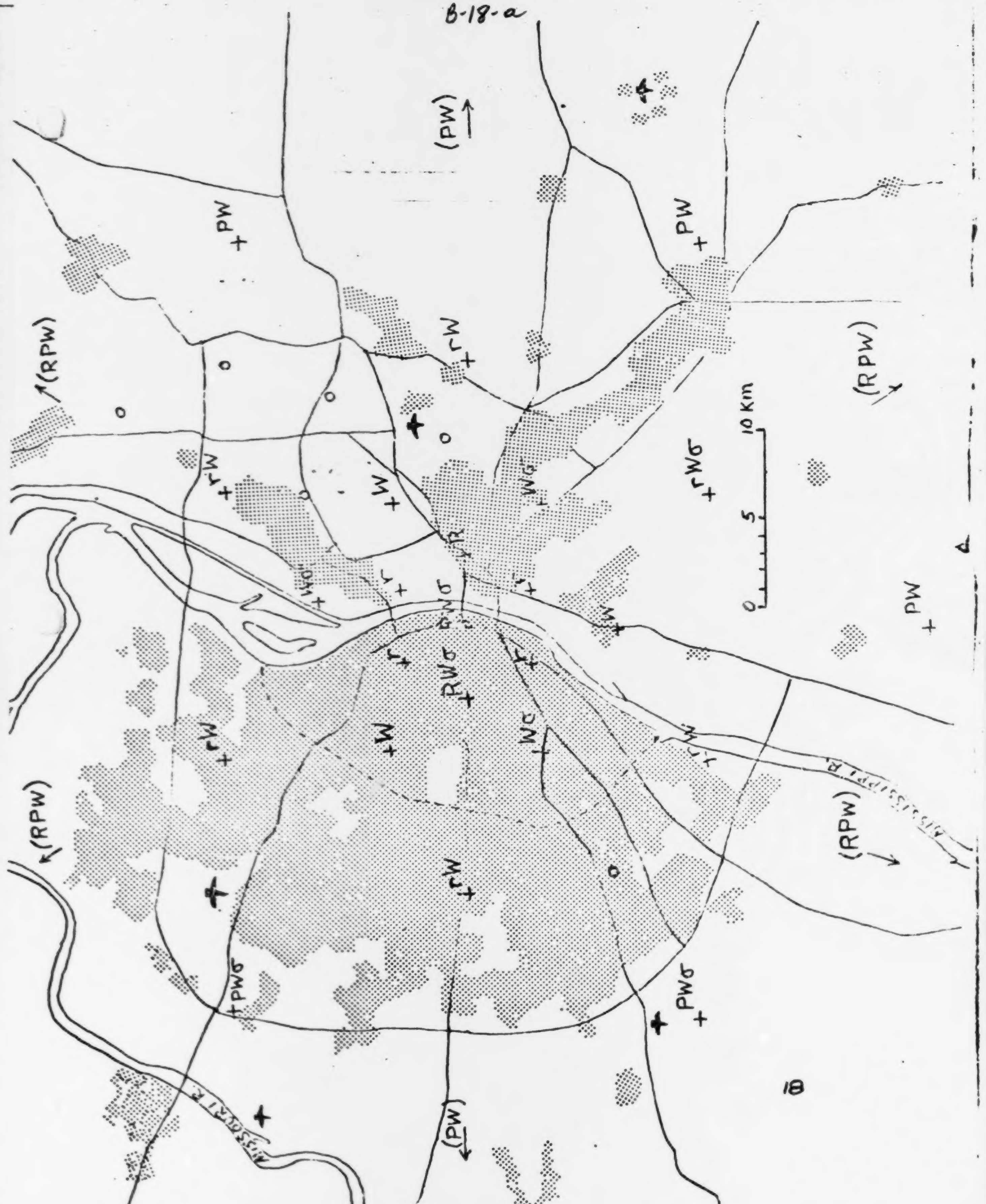
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two additional sites. Pressure measurements (P) will be made at the central site and selected outer stations. At three of the wind sites, the vertical wind component will also be measured, and the variances (σ) of all three wind components will be obtained for selected intervals. If two suitable tall towers can be located and installation of equipment is possible, temperature and temperature differences between levels will be measured, as well as the three wind components and their variances. There are no suitable towers in the main urban area, but some may be found in the 15 to 30 km range from downtown.

Discussion.-- The station density within the central 15 km is greater than that outside, in accordance with the first criterion discussed earlier. The most distant sites are only 30 km from the central site. The savings on communications and travel by not having permanent stations at greater distance should be substantial. Some sampling should be performed at distances as far as 150 km to study transformation processes on as long a time scale as possible, but is is more practical to use mobile samplers for ground-level measurements in such special studies.

Special-purpose local additions to the network to estimate spatial variability are not shown in the figure; the sites for such measurements can be selected when details such as the pollutants of interest and spatial configuration are settled upon. It may also develop that some air quality measurements might be deleted at certain sites, if this would help conserve resources.

As to siting requirements, the primary need for the air quality sampling is to avoid domination by local sources. For example, a street-side location would be a poor choice for obtaining measurements of primary automotive pollutants, except that such a location might be desired for a special-purpose local addition. It probably will be impossible to avoid some local influence, but it is not practical to derive criteria to quantify such influences. For the meteorological measurements, the siting requirements are determined by the geometry of the immediate area, rather than by pollutant emissions. For radiation measurements, an unobstructed exposure to the sky is required. For wind measurements, an unobstructed horizontal fetch, preferably over a homogenous surface, is required, since the wind data are to be used to determine the transport wind. For pressure measurements, the main requirements are to avoid major altitude differences and locations where major ponding of cool drainage air might occur.

To satisfy various siting requirements, not the least of which is site availability, there should be a reasonable degree of freedom to select sites within a general area surrounding each location indicated in Figure 3. For the close-in sites, a radius of a few blocks might constitute a reasonable limit, whereas for the most distant sites, a radius of 2 km or more would be acceptable. It should be emphasized that a regular geometry (e.g., equilateral hexagons) serves no great purpose. The hexagonal arrays shown should be considered only a general guidance for siting. If no suitable sites can be found within an acceptable radius, two options exist. The simpler is to omit the site and, perhaps to use the proposed equipment for either supplementing the array of additional sites or for establishing special-purpose local additions. The second option is to adjust the locus of acceptable sites for nearby sampling locations.

The locations of existing air quality monitoring stations will be considered in the final siting of the RAPS stations. Such networks include:

1. St. Louis City Division of Air Pollution Control, three stations.
2. St. Louis County Air Pollution Control Division, five stations.
3. Illinois Environmental Protection Agency, three stations.
4. EPA CHESS (Community Health and Environmental Surveillance Study) four stations.

These stations do not provide all the measurements required by RAPS and the data are not in comparable format. Some of the stations however, measure several of the same parameters and the data can be used to supplement the RAPS data, perhaps even eliminating the need for one or two RAPS stations. There are no plans for consolidating these networks into a single system, but data will be shared as needed. Both St. Louis County and the State of Illinois operate a number of high volume samplers in addition to the above air quality networks.

The fixed network is intended to provide nearly continuous data. As previously mentioned, long-range transformation studies could best be performed using mobile samplers for ground-level measurements. For tracer studies, some of the fixed network sites could serve as sampling locations, but many more tracer sampling sites would have to be selected for any given day's operations.

Facilities for Measurements above Surface

The horizontal distribution of pollutants at or near ground level is only a portion of the information needed on pollutant transport and transformation. Most atmospheric motion is horizontal, but wind direction and speed, air turbulence, and pollutant characteristics and concentrations all vary with height above the surface. Day-to-day variation occurs in the maximum heights to which pollutants rise and are transported. It is therefore important that vertical soundings of essential atmospheric parameters be made on a regular and frequent schedule.

Current plans call for a network of three or more stations that will make regular soundings of wind, temperature, humidity, and pressure at 6-hour intervals and more frequently on selected days. The station locations will be separated by at least 25 km, bracketing the central urban area. Soundings will be recorded to at least 3 km, or to the height of the mixing layer if it is higher than that. Regular helicopter or aircraft soundings will be made for the collection of air quality information, weather permitting. It is intended that such soundings be made at several locations around the St. Louis area and up through the height of mixing.

Nonroutine Data Acquisition

The emissions inventory will require operation of stack monitors or other instruments where justified. Some plants can provide adequate hourly emission rates, and other emissions may be calculated from fuel consumption or plant process schedules. Aircraft photography and possibly airborne radar or other devices will be used to study surface traffic characteristics on streets, rivers, and railroads. Air and airport traffic information is expected to be readily available.

It is anticipated that several expeditionary investigations will be planned and carried out during the full-scale operation of the telemetered surface network. The objectives will vary but may include collecting atmospheric chemistry information on additional pollutants, observing concentrations of selected pollutants with greater precision, tracing the chemical and physical transformation of pollutants that have been tagged, or measuring the dispersion of pollutants under selected meteorological regimes. These field expeditions may involve use of fixed-wing aircraft, additional balloon or helicopter soundings, mobile chemistry laboratories, and lasers.

Field tests of more sophisticated air pollution equipment are expected as these items are developed. The St. Louis Facility will provide the opportunity to compare new instruments with standard or present generation equipment. Such remote sensors as lidar, acoustic sounders, and radar are expected to be used.

Data Storage and Retrieval

The data from the fixed monitoring network will be telemetered to a central computer facility which will control the network operation as well as clean and store the information.

All data will be automatically identified, permitting the addition of data from other sources. It is currently planned to add all RAPS information, including sounding, aircraft data, tracer data, and chemical and ecological sample analyses, to a common data bank.

The entire data bank will eventually be available to qualified users. Participating EPA Divisions and their RAPS contractors and grantees should have direct access, using their funds accounting code. The location and design of the data bank will be part of a thorough data management plan, which will be prepared early in the study.

3. MANAGEMENT AND SCHEDULING

RAPS will constitute the largest and most comprehensive scientific investigation and analysis of the phenomenology of air quality and pollution yet undertaken. Field data describing air quality, meteorology, and other pertinent factors will be obtained by a data acquisition and processing system unprecedented in the study of air pollutants. This critically important effort must receive the most careful planning and management, both before and during its execution, to ensure effective utilization of the facilities and personnel assigned and the most appropriate expenditure of funds.

The RAPS research and development program is planned as a five-year integrated operation. It was initiated in July 1972, with research operations begun at that time. All of the field data for RAPS will be acquired within the St. Louis Air Quality Control Region by means of a measurement program established as the St. Louis RAPS Facility. The scope of RAPS is such that continual review and modification will be required of all schedules, costs, and other factors presented in planning documents. This aspect of the project is of particular importance in relation to the estimated activation schedule, since many policy and design considerations are present, not all of which can be anticipated or evaluated at this time. Moreover, several important parts of the schedule, and perhaps certain costs, will depend on the actual conditions found to exist at later times. Accordingly, the planning factors presented here are regarded as having an accuracy and reliability suitable only for general planning purposes.

PROJECT MANAGEMENT AND STAFFING

Responsibility for executing RAPS has been assigned to EPA's National Environmental Research Center (NERC) in Research Triangle Park (RTP), North Carolina. The NERC effort will be supported by other EPA organizations, including the Office of Air Quality Planning and Standards (OAQPS) also located at RTP; the Office of Research and Monitoring (OR&M), and the NERC located in Las Vegas, Nevada. In accordance with EPA research management procedure, a Project Element Director has been appointed by the Director of the NERC and given the responsibility for getting the study into operation and coordinating its several components.

The research program is distributed among participating EPA offices and laboratories (associated with NERC-RTP unless otherwise specified) as follows:

1. Meteorology Laboratory: Responsible for determining the path and dispersion of pollution in the presence of typical atmospheric conditions and developing mathematical simulation models of transport, dispersion, photochemistry, and other processes influencing the concentrations of pollutants at receptors.
2. Chemistry and Physics Laboratory: Responsible for characterization of gaseous and particulate pollutants and their transformations, development of reaction rate and mechanism data for the modeling program, and development of instruments and analytical methods needed to determine the physical and chemical character of pollutants at receptors.
3. National Ecological Research Laboratory, NERC, Corvallis: Responsible for studying the removal and redistribution of pollutants by the ecosystem.

4. Monitoring and Data Evaluation Division, OAQPS: Responsible for the design and initial collection and testing of the emission inventory and for the development of techniques for obtaining source inventories.

5. Implementation Research Division, OR&M: Responsible for studying the costs and benefits of controls for each source or set of sources for different kinds of abatement practices and levels of control.

6. Quality Assurance and Environmental Monitoring Laboratory: Responsible for development of monitoring technology and network design for model verification.

7. Human Studies Laboratory: Responsible through its CHESS Program for studying the effects of pollution on human epidemiology and respiratory processes. The CHESS Program will use air quality information gathered in RAPS and will contribute information on the cost of air pollution in terms of human health.

8. NERC-Las Vegas: Responsible for developing and employing airborne air pollution and meteorological sensors for the collection of information above the surface.

The Directors (or their representatives) of the participating offices, Laboratories, and Divisions constitute a RAPS Steering Committee that periodically reviews the progress of RAPS and contributes to major decisions affecting the study. Specialists from these Divisions are selected for working groups to accomplish major tasks that are beyond the capability of the RAPS staff.

The Project Element Director works through these participating divisions and a prime contractor to accomplish the RAPS Program. He is assisted by the following staff at RTP:

1. Research Coordinator: The research coordinator provides scientific liaison between the participating Divisions and determines that all RAPS research activity is consistent with RAPS purposes. He identifies areas of information that are not being adequately provided for. He works with NERC program managers to furnish the budgeting and planning information needed by EPA Headquarters.
2. Data Manager: The data manager converts participants' requirements for information into design and operation specifications for the data processing, formatting, storage, and retrieval system. He assists participating divisions and their subcontractors and grantees in obtaining and interpreting needed data.

and by the following staff in St. Louis:

1. Assistant for Research Operations: This physical science administrator oversees the research support activities of the prime contractor in matters affecting the scientific applicability of the facility data and assists participating Laboratories in arranging for and carrying out expeditionary data acquisition.
2. Assistant for Facility Management: This data management engineer oversees the network operation and maintenance and the use of special or expeditionary instrumentation to ensure data applicability and quality. He oversees the on-site data processing, storage, and retrieval activity.
3. Administrative Assistant: In addition to normal administrative matters, this employee monitors contractual programs and maintains fiscal records for the facility.

The design, installation, testing, operation and maintenance of the St. Louis research facility will be by service contract with a firm to be selected through normal competitive procedures. The selected firm will design, install, and operate the data acquisition system and provide the specialized scientific and engineering services needed to implement the study in the St. Louis area within the specifications and guidelines provided by the Project Element Director and his St. Louis staff and subject to their review.

The prime contractor's responsibility, which will be detailed in the contract work statement, will include such activities as the design and procurement of RAMS instrumentation, communication equipment, and data processing equipment, and receiving and installing it at instrument sites and at the central facility. The contractor will assist EPA in acquiring instrument installation, and after installation will provide system checkout and operational testing to ensure satisfactory operation.

During the RAPS operational periods, the prime contractor will operate and maintain both the permanent data acquisition facility and the equipment and sites needed for expeditionary data acquisition. He will assist research personnel, as required, in sample collection, analysis, and interpretation. He or his subcontractors will carry out assigned RAPS investigations and provide support for EPA investigators. The RAPS facility will be available for use by other Federal agencies and their contractors or granties on an interagency transfer of funds.

FACILITY ACTIVATION SCHEDULE

July 1972 Set up project office in St. Louis. Prepare request for proposal (RFP) and study plan

Summer and Autumn 1972	Exploratory field measurements
November 1972	Issue RFP
January 1973	Receive proposals for evaluation
June, 1973	Award contract
Summer and Autumn 1973	Preliminary field experiments
June 1974	Commence routine data acquisition (partial network)
Summer 1974	Selected field experiments
October 1974	Complete network and field experimental program in operation
June 1977	Close down St. Louis field program

Critical assumptions in the activation schedule are described in the following paragraphs.

The design, procurement, installation, and operational acceptance tests of the instrument prototype stations were estimated by SRI to require about 44 weeks. The critical path through the scheduling network consists almost exclusively of the digital data terminal equipment. This situation is caused primarily by the fact that all air quality and meteorological instruments are considered to be standard catalogue items with relatively short procurement times, whereas the digital data terminal equipment consists of a combination of standard and specially designed equipment. The latter group of digital data equipment causes much of the length of the of critical path, especially when combined with the design decisions associated with the telephone communication system.

The air quality instruments to be used on RAPS are being selected as a result of performance testing by the Research Triangle Institute, Research Triangle Park, North Carolina, under an existing EPA contract (68-02-1011). The testing is expected to save time in bringing the entire system into operation. The equipment linking the meteorological and air quality instruments with the digital data equipment will not have been tested, and correction of design flaws in it could lengthen the shakedown period.

PROJECT COSTS

Funding for RAPS has been established at approximately $5 million per year for 5 years. Within this level, an adequate measurement facility must be purchased and placed into operation during Fiscal Years 1973 and 1974 (FY 73 and 74). Funds must be allocated for its continued operation and for a number of expeditionary data gathering efforts during the following 3 years, through FY 77.

Using the SRI estimates of unit cost, a 30-station network should cost approximately $2.5 million. Associated facilities, such as laboratory equipment, central data processing equipment, helicopter and aircraft instrumentation, and equipment of special surface vehicles, including mobile laboratories, should result in a total facility cost of approximately $2.7 million.

Again using the SRI estimates, the costs of operating personnel, maintenance, communication, rentals, expendables, and management should total approximately $1.6 million per year of full operation. Since some on-site operations, such as taking the emissions inventory, and making preliminary studies of the chemical character of pollutants and the behavior of the atmosphere, will proceed during FY 73 and 74, there will be a gradual build-up of operating expenses from project initiation.

A number of key studies involving photochemical processes, gas-to-solid chemical transformations, and instrument development must be accelerated during FY 73 and 74 in order for their results to contribute to the success of model development in later phases of the study. The major research effort, however, will occur later in the program and will be based on data from the field operation. Annual research costs are expected to range from approximately $2.3 million in FY 73 to nearly $4 million in the later years of the study.

THE RESEARCH PLAN

The research plan for RAPS has been developed to advance the existing state of knowledge concerning air pollution on a broad front, in order that the primary objectives of the study may best be attained. The plan is presented as interrelated series of work areas, with the major projects within each area listed to more specifically indicate the kinds of studies being planned. Designation of these various work areas is based primarily on the technical specialties involved, but the interdependency between work areas and projects requires some degree of arbitrariness in the format of the work plan presented. The three work areas constituting atmospheric processes - transformations, dispersion,- and removal- are intimately interdependent in the real atmosphere. These three areas, together with emission inventories and mathematical simulations, constitute the technological core of the RAPS. Extensive coordination between these work areas is required if any real advances in simulation modeling for control strategy formulations are to be achieved. It will not be sufficient only to develop simulation models that yield output calculations acceptably close to observed monitoring data; each module in the model (emissions, transformations, etc) should be verified independently, if at all possible, in order that compensating errors in input data and/or module formulation do not go undiscovered. In many cases, development of the modules, or submodels, will constitute an integral part of the required projects since the processes to be described can be understood only in terms of hypotheses set forth in terms of these submodels. The hypotheses developed can then guide the specification of requisite experimental data.

The RAPS will not be conducted in isolation from other activities of the several EPA organizational components contributing to the total research plan (Chapter 3). Indeed, these other activities, in support of various other objectives, will occupy more of the resources allocated to each organizational component that will the RAPS activities. The coexistence of RAPS and these other activities will be mutually beneficial, however, in that there exists some overlapping of objectives. In this sense, the contribution to RAPS from the organizational components involved considerably exceeds the resources formally earmarked for the study.

While the evolution of new measurement methods and instrumentation will be recognized during the course of the study, significant support for fundamental projects to aid this evolution is outside the main scope of RAPS. Use will be made of existing instrumentation to the maximum extent practicable, but promising new methods, i.e., those with an expected high return in terms of reduced time or expense or improved data will be considered for support as the study progresses. For example, the feasibility of a method might be demonstrated through research support outside of the RAPS framework, whereas the prototype development of instrumentation using this method could fall within the RAPS effort.

In the following material, the principal projects withih the work areas are indicated by sequential numbering within the hundred series representing the work areas. Thus, within the work area 200, Atmospheric Transformations, the second project listed, Aerosol Studies, is given the number 202. This number system is similar to that used in the SRI Prospectus, but since the organization of material here differs significantly from that given in the Prospectus, there is no direct correspondence between the two numbering systems. There is likewise no correspondence with task numbers listed in certain internal EPA planning documents (ROAP's); the projects here listed generally included a number of such individual tasks.

WORK AREA 100--EMISSION INVENTORIES

Pollutant emissions from both moving and stationary sources are an obvious ingredient of any air pollution situation. A detailed, ongoing air pollutant inventory program must be an integral part of the RAPS program. In order to support short-time simulation modeling efforts, this program must include, in addition to data on source emission rates, techniques by which emission rates can be determined for periods as specific as a given hour of a given day. Thus, the emission estimation submodel will have two major components: the inventory of source emissions and the development of techniques by which this inventory can be used to estimate emissions over specific time periods.

It is expected that the RAPS emission estimation techniques, including the programs for inventorying, data handling, and data storage, will also have wide applicability to regional air pollution control programs because of the general importance of emission assessment in a control operation. Thus, the techniques for emission assessment will be a significant and relatively early area of RAPS technology development that can be applied to the nation's air pollution control programs.

101--STATIONARY SOURCE INVENTORY

Specific Objective: Develop and maintain a comprehensive inventory of emissions from stationary sources.

Discussion--Techniques by which emissions from stationary sources may be estimated have undergone continuing development in recent years. At the present time, virtually all such sources can be potentially identified by inventory procedures, and the substances being emitted can be cataloged. Since it is impractical to identify each individual source and specify its emissions, together with fact that most pollutant simulation models do not use such detailed information, only the larger contributors are individually identified and treated as point sources, while lesser sources are grouped and treated generally as area sources. Determination of rates of pollutant emissions from stationary sources is a widely varying mix of engineering measurements, interpretation of published and specially collected statistical data, and artful guesses. Emissions from the bulk of sources, particularly area sources, are usually calculated on the basis of emission factors, which express the emission of a particular pollutant as a fixed ratio to fuel consumed or to product output. While these factors are based to the maximum degree possible on actual measurements, they have, of necessity, been extended to estimate emissions for which only the sketchiest of engineering information is available. For both point and area sources, the temporal resolution is not presently adequate for calculating pollutant concentrations for periods as short as an hour; in many cases, only seasonal resolution is available. Better resolution can be obtained for some types of sources, e.g., the bus-bar output at a power generating station is highly correlated with stack emissions and, for emissions associated with residential fuel consumption, janitor functions have been developed to describe diurnal variations of emissions. Since area sources are treated as aggregates, the accuracy of emission estimates for each area decreases as that area is decreased to obtain more spatial resolution. For most emissions, detailed surveys should be able to provide spatial resolution down to the scale of the individual sources; such surveys have not been performed, not only because it would be a formidable task, but, more important, because there has heretofore been no need for such detail.

Method of Accomplishment--Since the format and requisite detail of the emission inventory depends on how the data are to be used, an in-depth survey of potential uses of the data will be made. This will permit specification of the emission inventory, including temporal resolution, spatial resolution as a function of location within the RAPS region, and precision of estimates for individual or grouped pollutants. Data coding forms will be designed, and a system for computer storage and retrieval of data will be developed. Existent source data will be located and converted to useable format. Techniques for converting source data to emission data will be updated and applied. Field work will be performed to sample actual emissions from representative sources in order to derive emission factors for a number of pollutants. Diurnal and weekly emission patterns will be developed, and, where possible, verification data on actual emission rates will be obtained by aerometrically determined mass flux data for comparison with calculated rates.

Project Schedule--Late in 1972, the existing source inventory will be made available on punched cards or tape for initial atmospheric modeling activities. This inventory is a result of extensive in-house and contractor efforts undertaken by the Office of Air and Water Programs, EPA. Preliminary inventory work for RAPS will begin early in 1973 with identification of users and needs, collection and consolidation of all existing data, design of data coding and specification of handling system, and collection and documentation of existing emission model information. Collection of stationary point and area source data for diurnal variation will begin in mid 1973.

DRAFT

102--MOBILE SOURCE INVENTORY

Specific Objective--Develop and maintain a comprehensive inventory of emissions from mobile sources.

Discussion--Some of the same problems are encountered in developing an inventory of emissions from mobile sources as are encountered in stationary source inventories, primarily in determining emission factors and secondarily, in spatial allocation of these sources. The temporal resolution obtainable is generally somewhat better than that for stationary sources since the bulk of mobile source emissions are from highway vehicles, which can be monitored with traffic surveys. In determining motor vehicle emission factors, two approaches can be used: emissions per vehicle mile, and emissions per unit of fuel consumed. Both depend, of course, on the model, make, year, and condition of the vehicles, as well as on traffic pattern and density. Because of the changing mix of vehicles and traffic flows, factors developed for one area and time cannot be applied for others; mobile source emissions inventories require a more nearly continuous updating to maintain their validity than do stationary source inventories. Similar methodology is applied to locomotives, aircraft, and vessels.

Method of Accomplishment--The steps leading to development of a data storage and retreival system outlined for Project 101 will include mobile source emissions as well as stationary source emissions. Field studies will be made to describe representative traffic patterns, probably for four days of the weekly cycle; airborne radar measurements are expected to be extremely useful in such studies. It may be necessary to supplement existing emission factor test data if it is found that information for mini-driving cycles or vehicle mixes for the St. Louis area are insufficient. In such cases, individual automobiles will be tested.

Collection of source inventory data for railroads, airports, and vessel ports will also be undertaken together with source testing and duty cycle determination for locomotives and vessels (and aircraft if necessary). Data handling is included in Project 101.

Project Schedule--Initial steps in the mobile source inventory are included in Project 101. Cooperative effort with the Department of Transportation (DOT) will increase effectiveness of the study; EPA will be responsible for highway vehicle inventory and testing and DOT for off-highway vehicle inventory and testing. DOT will also be involved in emission model validation activities, probably supplying the mobile instrument unit. EPA efforts began with hardware feasibility studies for airborne radar surveillance in 1972 and collection of traffic survey and operational data will begin in the summer of 1973. Current automobile testing efforts are underway in ST. Louis and will continue for several years. DOT efforts will begin in mid 1973.

WORK AREA 200--ATMOSPHERIC TRANSFORMATIONS

A complete inventory of pollutant emsssions is only the starting point in describing the atmospheric pollutant burden. A description of the chemical and physical transformations of the pollutants is the next essential step. The entire lifetime cycle from emission to removal must be known for each principal air pollutant before mathematical simulation models can make fully successful predictions. A complete understanding of pollutants, reaction products, reaction intermediates, and scavenging mechanisms is necessary in the design of control stategies, in the development of abatement procedures, and in land use planning.

The atmospheric transformations program will yield information on pollutants for which air quality criteria have been issued, as well as on pollutants that are measured infrequently, or not at all. Six major categories of pollutants will be considered in detail in this program: sulfur oxides, (SOx), nitrogen oxides(NOx) hydrocarbons, particulate matter, photochemical oxidants, and carbon monoxide (CO). Many of these pollutant categories are so interrelated and interreactive that a clear-cut separation between them in either discussion or study is neither possible nor desirable. The study of particulate material, including its concentration, size distribution, and composition, is of particular importance in understanding scavenging mechanisms. The studies of interreactions of NOx, hydrocarbons, and photochemical oxidants must be integrated to characterize photochemical activity in the atmosphere.

201--POLLUTION DISTRIBUTION

Specific Objective--Survey species and distribution of gaseous pollutants

Discussion--Data are needed on the amounts and distributions of nitrogen acids, NO, NO_2, CO, SO_2, ozone (O_3), peroxyacetyl nitrate (PAN), and hydrocarbons. Especially needed is a detailed compositional analysis of the hydrocarbons. From this, concentrations ratios between inert and reactive hydrocarbons can be calculated for various geographical locations. The ratios will provide information on the age of the polluted air mass and on the general trend of the air movements. The measurements need to be made at heights above the ground as well as at ground level. In addition, the detailed hydrocarbon analysis will provide quantitative data on atmospheric loading from various sources.

Special emphasis will be placed on measurement of tracer gases which may be useful in the study of the dispersion of the urban pollution plume from the metropolitan area. Three tracers are of main interest: acetylene, carbon monoxide, and the freons.

Acetylene has several properties which make it of special interest for tracing the pollution from combustion sources: (1) Acetylene is prominent in automobile exhaust and other combustion effluents; (2) No natural sources of acetylene are presently known; (3) The lifetime of acetylene in the atmosphere appears to be long enough (several months) to allow tracing of the urban pollution plume, but short enough to prevent its general buildup in the atmosphere.

Carbon monoxide may also serve as a tracer of the urban pollution plume, but it may not be as useful as acetylene. There are substantial natural sources of CO, and there is a general atmospheric backgound of about 0.1 parts per million (ppm.).

Freons are of interest because: (1) They are being used in increasing quantities by people. (2) They are long-lived in the atmosphere. (3) Extremely sensitive methods of detecting the freons are available.

The ratio of the C-12 and C-13 isotopes in a CO sample can indicate whether the CO is natural or man-made. Such indicators have been studied by the Argonne National Laboratories under an interagency fund transfer. It is planned to continue the study as part of this task. If a natural background of acetylene is detected, the isotope ratio study may be extended to that compound as well.

Method of Accomplishment--Two research vehicles were moved into the St. Louis area in the summer of 1972 and were operated through summer and fall. A central operating location on the grounds of St. Louis University was chosen, but sampling was also performed at a number of points in the metropolitan area. For measuring labile pollutants, such as O_3, a vehicle carried the instruments to the chosen location. For measuring pollutants that can be transported in bags, the samples were collected and returned to the instrument site for analysis. Most of the equipment for this survey program is already available within the Chemistry and Physics Laboratory (CPL). It is essentially the same equipment used at Denver, Colorado, in October 1971. The instruments include a gas chromatographic system with a computerized automatic data processor, a Fourier transform spectrometer with a

1-kilometer (km) long-path cell, and a variety of specialized monitoring instruments such as chemiluminescent NO_x and O_3 monitors, recording nephelometers, and particle collection and analysis equipment. One mobile laboratory is self-propelled, while the other is a trailer.

As mentioned, the isotope ratio method of identifying pollution sources will continue to be studied under fund transfer by Argonne National Laboratories.

Schedule Project--This task began in the summer of 1972, using facilities already available within CPL. As the RAMS stations come on line the studies will be closely coordinated with the measurements at these stations, and will be replaced by them whenever it is practical. The spectroscopic and gas chromatographic measurements are probably too specialized for the network operation and therefore may need to be continued independent of the network.

Project 202 -- Aerosol Studies

Specific Objective: Characterization of the St. Louis Aerosol.

Discussion--No mathematical model of photochemical pollution can be realistic unless it can predict visibilty loss, metals transport, and the formation and decay of noxious fine particles. These matters must therefore be pursued in the development of the regional air quality simulation model.

Fine particle pollutants are the most obvious, as well as the least understood component of the polluted air. Although the particulate portion of the pollution may only be a few percent of the total pollution mass, it is an extremely important few percent. The most easily noted effect of air pollution is the visibilty loss, and this is almost entirely due to the fine particles. Furthermore, the particulate matter plays a significant role in the removal of the gaseous pollutants. It appears likely that particles are the principal sink for NOx and SO2 and that they may also be important sink for organic gaseous pollutants.

Research on atmospheric fine particles has to be conducted mainly in the field because of the difficulty of synthesizing pollution aerosols in the laboratory. Thus CPL and the California Air Resources Board are currently engaged in a major field study of the California aerosol. The St. Louis regional research program must continue the development of a visibilty submodel and an aerosol dynamics submodel. As these submodels are developed, they must be factored into the overall regional air quality model.

Method of Accomplishment-- Several research stations will be set up in St. Louis in the summer of 1973. This will be done by means of research grants to an experienced team of investigators brought together from several

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parts of the country. The group will put a concentrated effort in the summer and fall of 1973 in order to get the measurement program under way. They will then shift the burden of routinely collecting aerosol data and of doing preliminary analyses of those data to the principal contractor. The grantees will continue participation in the program beyond the First Year. They will rely on the contractor for program continuity, but will bring in university personnel for special projects and for concentrated summer studies.

Measurements will be made of aerosol number and mass as a function of size. Aerosols will be collected and analyzed for sulfate, nitrate, ammonium compounds, and organic composition. Aerosol composition will be studied as a function of particle size. Visibility measurements will be made and correlated with the particle size, mass, and composition data. Measurements of selected gaseous aerosol precursors will either be acquired from the general sampling network or will be conducted as part of the comprehensive aerosol study. Relationships among the gaseous pollutants and the particle composition will be studied. Instruments to be used in the study will include the condensation nuclei counter, the multiwavelength nephelometer, the mobility analyzer, the optical particle counter, the high volume impactor, the infrared spectrometer, and the X-ray fluorescence spectrometer.

Instruments to be used in the field will be housed in moveable laboratories. These will be operated by a combination of university personnel, contractor personnel, and CPL personnel. Instruments tested and perfected during the 1972 California aerosol study will be moved to St. Louis in 1973. Laboratories in the central RAPS facility in St. Louis will be needed for analysis of collected aerosol by X-ray spectroscopy, gas chromatography, and infrared spectroscopy.

A highly qualified scientist will be funded by a grant to Washington University in St. Louis to work on the aerosol characterization program, his work will include limited assistance to other investigators.

Project Schedule--Grants will be awarded in FY73 so that the experimental program can begin in earnest in the summer of 1973. As the RAPS monitoring network becomes operational, the aerosol characterization program will be expanded and integrated with the network program. By summer of 1974 it is expected that an intensive aerosol study will be underway. This study will involve a considerably larger amount of sampling and analyses than the special studies of 1973.

PROJECT 203--KINETICS SUBMODELS

Specific Objective--Provide Data in Support of the Development of Kinetic Sub-Models for the St. Louis Atmosphere.

Discussion--The study of captured air samples is necessary in the further development of chemical kinetic models for the atmospheric system. These samples may be unchanged ambient air, ambient air with added pollutants, or artificial polluted air made up from bottled gases.

Most past studies of the reactions of polluted air have been carried out in the laboratory smog chamber. Transformation processes have been studied under precisely known reaction conditions to test and validate photochemical submodels. Artificial ultraviolet light and tank gases have been used. Certain reaction parameters have been varied to define effects.of reaction variables on atmospheric transformation processes. Material balances of chemical elements have been obtained.

A second technique of study in the past has been the use of large plastic bags in which a controlled ambient air sample experiences normal conditions including the natural spectral distribution of light and the normal diurnal light intensity cycle, as much as possible. Furthermore, unlike tank air, the bag sample has the humidity, condensation nuclei, and range of minor constituents typical of ambient air.

A third type of chamber study of pollutant transformations has recently been initiated at the University of North Carolina under a research grant from CPL. An outdoor chamber in the form of a large plastic enclosure has been set up. This enclosure has two compartments of 7000-cubic-foot (approximately 200-cubic-meter) volume each. The dual chamber will allow comparisons between the reactivities of natural air and air whose pollutant concentrations have been altered. Direct tests will be conducted to determine the effects of control of such pollutants as hydrocarbons and nitrogen oxides. Kinetic models will be tested by applying them to the transformations of the natural air with added levels of pollution. There will also be provisions for dynamic chamber runs in which the pollutant concentrations are programmed according to plan.

The chamber experiments must be supplemented by a continuous study of gas reactions and by measurement of reaction rates. It has become apparent that smog modelers are presently limited by the inaccuracy or unavailability of key rate constants. Where present experimental technique is inadequate for accurate rate constant measurement, there is a need for calculating the theoretical rate parameters. It is important that information allowing modelers to achieve a fit to chamber data and atmospheric data be obtained as soon as possible.

Method of Accomplishment--Laboratory smog chamber experiments and outdoor irradiations of captured air samples are both planned for the St. Louis program. The relative emphasis on each will be determined as the program progresses. Plastic bag irradiation studies were carried out in the summer of 1972 in connection with other field experiments. By mid-1973, the progress in the Univeristy of North Carolina outdoor chamber program should provide guidance as to the usefulness of such a program in St. Louis. A chamber study of one type or the other will then be contracted for.

CPL and existing contractors presently engaged in modeling will prepare a list of rate constants important in the chemistry of the regional atmosphere. A research institute or a university may later be engaged to carry out measurements of selected constants. It may become necessary for some rate parameters to be theoretically calculated from existing thermodynamic values.

Refinement of the St. Louis kinetics model resulting from the experimental program will generate new requirements and guide the selection of future experiments.

Project Schedule--A contract for kinetic submodel verification in smog chamber studies was awarded early in 1973. Additional contract and grant work in such areas as rate constant measurement and mechanism studies will be awarded subsequently.

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PROJECT 204 -- TRANSFORMATIONS OF POINT SOURCE EMISSIONS

Specific Objective: Identify NOx and SOx Transformations in Plumes.

Discussion--Plume transformations are an integral part of atmospheric chemistry and cannot be divorced from the overall set of transformations that take place in an urban atmosphere. The emission inventory can predict the types and amounts of pollutants released from stationary sources in a given area, but without knowledge of the transformations during plume dilution, one cannot properly use the emissions data in an overall atmospheric model. Several investigations have been made into the plume chemistry of SO_2 but such studies are far from complete. No research project has been conducted on the composition of NOx in plumes. However, several short instrument evaluation efforts with NO_2 correlation spectrometers have indicated elevated NO_2 levels in plumes. At least one set of airborne experiments also confirmed unexpectedly high NO_2 levels in the plume of a West Coast power plant. High NO_2 concentration in plumes could result in elevated ambient air levels and suggests a possible NO_2 fumigation problem.

Method of Accomplishment--It should be possible to measure the absolute concentration levels NO, NO_2, and SO_2 in plumes by state-of-the-art methods. Furthermore, instrumentation under development within CPL may extend the measurement capabilities to sulfur trioxide, sulfates, and nitrates in the near future. The measurement of plume dilution should be made by independant means. The following experiments may be included in this project:

1. Measurements of NOx and SOx in stack plumes by instrumental and reference NOx methods.

2. Injection and measurement of sulfur hexafluoride (SF_6) in plumes downwind to determine physical dilution. This technique already has been used successfully in recent plume studies of SO_2.
3. Aircraft flights through plumes with measurements by real time NO, NO_x, and SO_2 analyzers.
4. Aircraft or ground level measurements of NO_2 and SO_2 by long-path correlation spectrometry and possibly also by long-path second derivative spectrometry.
5. Collection of filter samples for laboratory nitrate and sulfate analysis.

The aircraft for experiments 3 and 4 should also be equipped with an integrating nephelometer for fine particulate measurement. Other analyses of filter samples in experiment 5 may also prove advisable. These additional requirements arise from the present difficulty in explaining the unusually rapid conversion of NO to NO_2 in plumes from reaction with oxygen or traces of ozone. Other homogeneous or heterogeneous reaction paths should be identified.

Project Schedule--Procurement and check out of instruments for real-time measurement of NO, NO_2, and SF_6 was begun early in 1973. Point sources where SF_6 injection systems can be operated will be selected later in the year, with initial field tests late in the summer or in the fall.

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Project 205 -- Spatially Averaged Pollutant Measurement

Specific Objective: Measure average pollutant concentrations over path lengths comparible with dimensions of modeling grids.

Discussion--In model development and model verification, it is desirable to have pollutant measurements averaged over the resolution element used in the calculations. Long-path laser absorption techniques appear to be the most promising method of obtaining such data. The laser method of pollution measurement has been under development for several years with DCP sponsorship and presently appears to be ready for application in the field. There therefore appears to be a fortuitous match between the needs of the St. Louis study and the readiness of the laser long-path method for field demonstration.

There have been several parallel laser developments that show promise. Each has some advantages and disadvantages, and the different types of lasers may be considered complementary rather than competitive with each other.

The tunable diode laser is probably the most advanced in its application to pollution measurement. It can be applied to any one of many pollutants, and it will operate with a high degree of reliability. However, the diodes are limited in power; propagation over a path as long as a mile may not be as easy as in the case of the gas lasers.

The CO_2 laser applies to a more limited number of pollutants, and it is a more cumbersome apparatus than the diode laser system; but, it does have the advantage of high power. The rare gas lasers can be included with the CO_2 laser to enlarge the number of pollutants to be measured, but they are only intermediate in power. The magnetically tuned rare gas laser has a special attractiveness because of its expected high specificity and sensitivity in detecting selected pollutants such as formaldehyde.

Method of Accomplishment--Laser systems will be built for field use by the contractors that have been mainly responsible for their development to date. These systems will be brought to St. Louis and installed and operated in the mobile monitoring stations being set up as part of the St. Louis network. The laser systems will be put into operation by the contractors that built them, with the assistance of personnel of the St. Louis facility contractor and under the general supervision of CPL personnel and the RAPS staff.

A transciever configuration, i.e. the transmitter and receiver at one location, will probably be preferred. The laser beam will be folded back on itself by means of a retroreflector. Two types of lasers will be used: the tuned CO_2 with various isotopic species and the current tuned diode. These systems are under development by two different contractors.

The operation of the laser systems from the network monitoring stations will permit checking of the laser readings against the readings of the more conventional measuring instruments.

The benefits of the laser program should be twofold: (1) The development of a technique of measuring averaged pollutant concentrations will be a valuable contribution to the modeling program. (2) The resulting advancement of laser technology for pollution measurement will be applicable in other situations in the RAPS program, including point sampling.

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Project Schedule-- Laser systems construction was begun in late 1972.

Testing and evaluation of both types of laser will be complete by mid 1974, at which time one or both types will be installed in St. Louis for operation by contractor personnel.

PROJECT 206--GAS CHROMATOGRAPHY AND INFRARED SPECTROSCOPY

Specific Objective: Analysis of trace contaminants is the St. Louis atmosphere by gas chromatography and infrared spectroscopy.

Discussion--Identification and analysis of trace contaminants will assist modeling efforts to evaluate the importance of various alternative reaction paths involved in atmospheric transformation and removal processes. Gas Chromatography is the most powerful known method of analyzing the atmosphere for gaseous pollution in trace amount. With appropriate sample collection and concentration steps, pollutants at dilutions in air as great as one part in ten billion can be measured. This is the level of contamination that must be measured in the St. Louis regional study. The weakness of the chromatographic method is that the elution time is the only characteristic property which distinguishes one compound from another. For complete and accurate work, therefore, an auxiliary method of peak identification is required. Infrared spectroscopy has been used for peak identification for many years and has proven to be one of the best methods. Its one drawback has been that it has required a relatively large sample for identification. The new Fourier transform spectrometers have now increased the detectability of very small concentrations of column effluent manyfold. The use of the latest chromatographs and the new spectroscopic method in combination with careful sample collection and concentration procedures should extend the chromatographic method to many additional trace pollutants. The chromatography-infrared method should also be capable of identifying compounds in the organic fraction of collected aerosols.

Method of Accomplishment--Several chromatographic systems are available for use within CPL. A portion of the needed Fourier transform spectrometer system is also available. This portion consists of the scanning interferometer, its control and detection system and the gas sampling system that accepts the effluents from the chromatographic column. At present, these portions of the spectrometer system share the computer and data system used in connection which the long-path cell. After initial work in the mobile laboratory, the gas chromatography-infrared spectroscopy studies be continued by CPL personnel at the central laboratory location in St. Louis. This will be done by moving the chromatographs and the optical system into the central laboratory facility and adding a data processing system.

Project Schedule-- The data system was purchased in 1972. During the summer and fall, 1972 the chromatograph and spectrometer were put into use in the mobile spectroscopy laboratory. The system will be installed in the central St. Louis facility as soon as possible, and will be operated with the assistance of contractor personnel.

Project 207--Photolysis Rate

Specific Objective: Develop Actinometer to Measure Rate of NO_2 Photolysis in Urban Air.

Discussion--The primary photochemical process in urban air is the photodissociation of NO_2. This reaction begins the cycle of transformation leading to photochemical smog. The rate of the NO_2 photolysis must therefore be accurately measured in order for the planned mathematical modeling to be successful. The measurements are necessary not only at ground locations throughout the region, but also at elevations above the ground. Sunlight sensors commercially available have several limitations when applied to the NO_2 photolysis problem: (1) they measure the light intensity without regard to the absorption curve of NO_2, and (2) they do not properly weigh the contribution of radiation from all directions. For RAPS, a new type of NO_2 actinometer is needed.

Method of Accomplishment --It is generally accepted by photochemists that the best way to measure the rate of initiation of atmospheric reactions is to expose a sample of NO_2 to the sunlight and observe its disappearance. Actinometers employing this method are used to measure light intensities in smog chambers. What is now planned is to develop an NO_2 actinometer for use in the outside atmosphere. Such a system was conceived and designed by Professor P. A. Leighton several years ago, but the design has not yet been used in the development of a test instrument. The central component of the proposed instrument is an NO_2 container which can receive light from any direction. The dissociation of the NO_2 in response to the light intensity is monitored by means of either the visible or the infrared spectrum. A prototype of the system will be built and tested as soon as possible. If successful, the system will then be used for the measurement of the actinic ra-

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diation in the RAPS.

Project Schedule: A contract for development and testing of a prototype instrument was let early in 1973. Purchase of additional systems for use in the field will take place in subsequent years if the prototype system functions as expected.

Project 208 -- Particle Measuring Systems

Specific Objective: Development and Acquisition of Particle Measuring Systems for Use in the Regional Air Pollution Study.

Discussion--The inclusion of particle dynamics, gas-particle interactions, and visibility loss in the atmospheric models will require new particle measuring systems. There is a need for systems to measure particle mass and size over averaging times of 1 hour or less for both ambient and source aerosols. There is a need to measure particle composition as a function of size over averaging times of 2 hours or less. There is a general need for instruments that will measure the particle content of the atmosphere with shorter averaging times than are available from present samplers. The early phases of the RAPS must therefore include evaluation and field testing of new systems for particle measurement. Automatic monitors are especially needed.

Method of Accomplishment--An advanced automatic particle size classifieranalyzer will be developed and evaluated. This instrument will measure particle totals and size distributions over averaging times of 1 hour or less for source aerosols. Analyses and further development of all known particle characterization methods, including impaction and/or filtration samplers, quartz crystal samplers, vibrating filters, beta gauges, and optical systems, will be undertaken. Prototypes of the promising systems will be built and tested early in the program so that the best of the new techniques can be put into operation in the monitoring newtork as soon as practicable.

Project Schedule: Development and testing of a new size-fractionating

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impaction system was begun in 1972. This work should be completed by mid 1973, leading to fabrication of prototype units which will undergo field checkout in 1974.

Project 209 -- Gas Measuring Systems

Specific Objective: Development and Acquisition of Advanced Instruments for Measurement of Gaseous Pollutants in the RAPS Monitoring Stations.

Discussion--Since the RAPS modeling effort will call for more reliable and more precise measurement of gaseous pollutants than ever before, the newest and most advanced instrumentation must be used in the monitoring network. Several promising instrument development programs are in an advanced stage where the building and testing of prototype hardware is now called for. Prominent among these new methods are those that use the electormagnetic spectrum, both in emission and in absorption. Emission by the pollutants is used in the chemiluminescence methods and in the laser-induced fluorescence method. Absorption by the pollutants is used in the tuned laser methods and in the gas-filter nondispersive infrared method. The laser methods have a special application within RAPS in the measurement of averaged pollutant concentrations over long paths, as outlined in Project 205. The nondispersive infrared methods have a particular promise for the RAPS study because they are passive methods amenable to automatic operation in monitoring stations.

The objective of the task is to carry the development of the new methods to an early conclusion and provide prototype hardware for field testing in St. Louis. When the performance of the new instruments has been demonstrted and their reliability has been established, instrument systems can then be purchased for routine use in the monitoring stations of the network.

Method of Accomplishment--Promising new measurement technique will be screened on a continuing basis, and instrumental development supported where feasible. Construction and evaluation of a nondispersive infrared

(NDIR) analyzer for NO_2, H_2CO, and other pollutants is underway. An alternate method will be explored for formaldehyde detection. An instrument for measuring acetylene at trace levels of 0.1 ppb will also be developed.

Project Schedule--A contract was awarded in 1972 for the NDIR analyzer; the analyzer will be tested during the summer of 1973. A contractor for the acetylene instrument will be selected in spring, 1973; delivery of this instrument should be made early in 1974, with field testing during the spring of 1974.

WORK AREA 300--ATMOSPHERIC STRUCTURE AND DISPERSION

Dispersion of pollutants in the atmosphere occurs principally in the planetary boundary layer, the layer which extends from the earth's surface to a varying height, usually 1 to 2 km. The structure of the boundary layer is a function both of large-scale atmospheric processes associated with global weather events, and of the local and regional transfers of heat, water vapor, and momentum at the earth-air interface. Because of the widely varying thermal and mechanical properties of an urban surface, there is a corresponding spatial variation of the boundary layer structure over urban areas. Knowledge of this structure, and of its spatial and temporal variations is quite limited because few measurements have been made, and even fewer studies have been carried out to relate the sparse observations to underlying physical causes. Since mathematical dispersion formulations are inherently limited in accuracy by the validity of the boundary layer structure, including its turbulent properties as implicitly assumed in these formulations, better descriptions of this structure are vital for model validation studies. In addition, a better knowledge of the influence of the urban surface on the boundary layer structure will permit application of results obtained in the St. Louis region to other areas, either existent or hypothetical.

Project 301 -- Climatology

Specific Objective: Develop the Synoptic Climatology of the Study Area.

Discussion--The best present approximation of diffusion climatology for an area is use of the Pasquill-Turner stability classification, with empirical, but largely unverified, adjustments for application to urban problems. The uncertainties of representativeness and validity of this method are well known, but better methods have not been used because of the serious lack of measured data. The continuous measurements from the monitoring network, together with data from the other sources that can be assembled, will provide a valuable resource with which the patterns of wind, temperature, and solar radiation can be described in terms of larger scale inputs of regional pressure gradients and radiation balance indices. While these patterns will be only for near-surface data, they will provide direct input for air quality simulation models and constitute the ground plane necessary for descriptions and simulations of the complete boundary layer structure (Projects 303 and 503).

Method of Accomplishment--Existent data sources in the St. Louis region will be surveyed, and limited analyses will be made to provide preliminary information for planning field experiments . Surface data from National Weather Service (NWS) and other sources, upper air data from the NWS radiosonde network, map analyses, and satellite observations will be assembled to provide descriptions and classification of the larger scale flow over the surrounding St. Louis region. As data from the monitoring network become available, analyses will be made to define the patterns and magnitudes of the urban-induced perturbations of the wind, temperature, and solar radiation fields.

Project Schedule--Preliminary climatological analyses will be started early in 1973. Compilation of data sources from the study area and the surrounding region will begin later in the year, and formats for inclusion of these data in a special data bank will be devised. Batches of data (either monthly or quarterly) from the monitoring network will be analyzed as they accumulate, with special analyses for specified particular types of periods being added during the continuing course of the study.

Project 302 -- Energy Balance Studies

Specific Objective: Determine the Components of the Thermal Energy Balance over the Study Region.

Discussion--The urban modification of the boundary layer is induced by the varying fluxes of heat, moisture, and momentum at the urban surface, together with alterations of the vertical divergence of radiant energy flux due to pollutant loadings and induced cloud formation. The major difference between urban and nonurban surfaces is the altered flux of heat to the atmosphere; this is particularly the case with lighter winds, which favor the occurrence of higher pollutant concentrations. However, the components making up the heat flux and their diurnal variations under differing weather conditions are very poorly known. At present, heat island studies are consequently limited to localized empirical relationships, which are only tenuously related to any physical understandings and have no general applicability to other urban areas.

Method of Accomplishment--A series of experimental projects is planned to measure the components entering into the heat balance singly and in combinations. Downward-directed solar and sky radiation will be measured at selected sites of the fixed monitoring network; the climatological analysis (Project 301) should indicate the representativeness of these measurements. Multilevel aircraft flights will be made to map the upward and downward radiant energy flux over the area. Spatial differences of radiant flux will be correlated with measurements of atmospheric aerosol. Experiments will be conducted to determine the partitioning of solar radiation between reflection and storage in structures making up the urban surface. Experiments will also be made to determine the thermal responses of various types of urban surfaces to the diurnal radiant flux variations and relate the responses to the heat storage and rates of heat loss. Artificial heat generation will be adapted from the emission inventories. On selected occasions, detailed sequential wind, temperature, and humidity profiles will be obtained over upwind and downwind cross sections to evaluate the horizontal advection and atmospheric storage terms of the energy balance. Interpretation of the experimental measurements will require development of a variety of submodels of radiant flux, subsurface thermal response, sensible heat transfer at building surfaces, etc.

Project Schedule--Limited measurements were made in the summer of 1972 to determine magnitudes of urban-rural differences to be found, and to assess the feasibility of proposed measurement methods. Downward-directed solar and sky radiation was measured at two sites in the St. Louis area, one rural and one urban; limited flights were made to measure the albedo of selected paths across the area and to measure the apparent surface temperature response with infrared thermometry. Temperature profile data will be obtained for selected materials under varying amounts of incident solar radiation to better define thermal characteristics of these materials.

Procurement of comprehensive air sampling packages for installation in two helicopters provided by NERC-Las Vegas was begun early in 1973. These will be field checked during the late summer and fall in the course of a study in the Los Angeles area prior to assignment to St. Louis.

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The packages will measure most of the pollutants for which measurements are planned at the RAMS sites, as well as temperature and humidity. Additional meteorological measurements from aircraft will be made. either by equipping additional aircraft or by use of existent instrumented aircraft. These measurements will include upward-and downward-directed radiation, infrared thermometry, winds, and turbulent fluxes, and will be made during selected periods of experimental studies through the remainder of the RAPS. All aircraft instrumentation will also be used in Project 303.

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Project 303 -- Boundary Layer Structure

Specific Objective: Define the Three-dimensional Structure of the Boundary Layer over the Study Region.

Discussion-- A major uncertainity in describing dispersion of airborne effluents, except over relatively short travel distance, arises from uncertainty of the turbulent flow in the dispersing layer. For daytime conditions, when a well-mixed surface-based layer usually exists the principal uncertainities are the depth of the mixing layer and the rate of air exchange at the top of this layer, which determines how fast the layer grows in depth; a secondary uncertainty is how much spatial variation of this depth will exist because of the urban surface. During normal nighttime conditions, when a stable surface-based layer develops over rural areas, an urban boundary layer develops because of the heating by the urban surface. Only fragmentary information is currently available on the complex structure of the urban boundary layer, and the dependence of this structure on vertical wind and temperature profiles over nonurban portions of the area.

Method of Accomplishment--To define the daytime boundary layer structure, measurements will be made to augment the data from the basic meteorological sounding network. Vertical temperature profiles from aircraft ascents will be made; aircraft traverses will be concentrated near the height of the top of the mixing layer to more accurately define its spatial and temporal variations. Vertical wind profiles will be obtained from tracks of ascending balloons, while tracking of quasi-horizontally travelling balloons will provide data on air trajectories and on potential

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circulations within the mixing layer, which may relate in part to the urban area influence. For nighttime conditions, the same measurements as for daytime conditions will be made, but since the depth of the layer of interest will be less, shorter vertical profiles will be made, but the number of profile sites will be increased. Aircraft soundings will be supplemented by remote sounding techniques. Lidar scans of the aerosol loading will be obtained for both day and night conditions to aid in definition of the existence or non existence of mixing through elevated layers. Both temporal sequences from a stationary system and spatial patterns from a moving system will be obtained. Measurements will be concentrated field expeditions of approximately 2 weeks duration each, with the periods of measurement chosen to be representative of the range of meteorological conditions experienced in the St. Louis area; about a dozen periods are planned.

Project Schedule: Procurement of a balloon tracking system began in fall of 1972. Arrangements for use of sounding systems for vertical profiles will be made during spring, 1973. Expeditionary measurements will be performed during the summer of 1973 to delineate the morning and evening transitions between the daytime and nighttime thermal structures, with more comprehensive studies planned as the full RAMS comes on line the following year.

Project 304 -- Tracer Studies

Specific Objective: Determine Patterns of Dispersion of Airborne Material over the Study Region by means of Tracer Studies

Discussion--Tracer studies provide a unique means to determine the integrated effects of transport and diffusion on the dispersion of materials over an area. The more complete description of the boundary layer structure available through Project 303 will provide a basis for describing the three-dimensional pattern of dispersion, and thereby considerably enhance the information available through analyses of the tracer tests to describe relative contributions from various source locations. At present, the fluorescent particle (FP) tracer system could be used without further development. However, for longer travel times under stable conditions with a ground-based tracer cloud, depletion by surface impaction becomes important, and, therefore, use of gaseous tracers is also required; in fact, order-of-magnitude values of particulate removal can be obtained by dual (fluorescent particle and gaseous) tracer releases under well controlled experimental conditions.

Method of Accomplishment--Tracer tests will be designed to provide information currently most lacking concerning dispersion of material. For daytime conditions, the rates and modes of vertical mixing within the boundary layer are the most uncertain elements to be determined. Tests with simultaneous release of several tracers at various heights or at various along-the-wind distances will be conducted, with various arrays of ground-level samples used in conjunction with aircraft sampling at various heights and downwind distances. At night, the vertical mixing is reduced considerably but displays a far greater spatial variability. In addition, the wind shear, both in direction and speed, introduces a dependence of the horizontal transport on height. Nighttime tracer tests will generally be point-sources releases, with arrays of ground-level samplers supplemented by ground-based sampling in the vertical (tethered balloons). In some cases, aircraft sampling can also be used at night. It is expected that a limited number of tracer releases will be made by injection into a source of actual pollution to specifically define contributions from existent sources. Tracers will also be used to define the urban plume for longer scale Lagrangian transformation experiments.

Project Schedule--A contract will be let in the spring of 1973 to develop samplers for gaseous tracers suitable for use in field experiments. Limited scope experiments will be started in 1974 with the objective of testing both fixed surface samplers and airborne samplers and developing procedures and techniques for more intensive field experiments in subsequent years. Since a knowledge of the boundary layer structure is required to fully analyze tracer test results, many experiments will be conducted in conjunction with measurements for Project 303.

PROJECT 305--POLLUTANT VARIABILITY

Specific Objective: Measure the Temporal and Spatial Variability of Concentrations of Selected Pollutants and Relate to Source and Dispersion Variabilities.

Discussion--The question of how representative, in space and time, a given observation of pollutant concentration may be is one that has hindered the development and validation of mathematical simulation models for over a decade. That there exists a monotonic relationship between the details available for model input and the accuracy of output calculations is taken as axiomatic, but the magnitude of improvement in the output as a function of increased input is largely unknown, and in fact should vary with the multitude of varying source-receptor relationships.

Method of Accomplishment--At selected sites of the monitoring network, arrays of samplers, probably as vertices of triangles surrounding fixed sites, will be set up at mutual distance of 1 to 2km. The pollutants to be measured remain to be selected, but should be limited to relatively slow-reacting species in order to minimize complications from transformation processes. A second criterion for selection of at least one pollutant is that a method for integrated path measurement between fixed sampling sites exists or is under development (see Project 205). More detailed emission data will be obtained for areas surrounding the sampler arrays, e.g., perhaps a house-by-house survey of emission sources over selected quadrants, or street-by-street traffic counts. Special wind measurements may be required to indicate the flow in the immediate vicinity of each sampler. Data will be analyzed to intercompare one-point measurements, multipoint measurements, integrated path measurements, and calculated values from simplified dispersion models, with the objective or defining the degree of determinacy that can be expected from model calculations.

Project Schedule--After a sufficient number of fixed network sites have been selected, they will be surveyed to determine suitability for installation of the planned special arrays. Up to three such arrays may be in operation at any one time. It is expected that 2 to 3 month's data, not necessarily continuous, from each array will be sufficient; it is expected that some of the arrays will be relocated, so as to provide data for about half a dozen source-receptor combinations.

SERIES 400 -- REMOVAL PROCESSES

Pollutants are removed from the air by respiration, by surface assimilation of air-deposited materials, and by uptake of precipitation deposited material. The effects on human health will be studied as part of the CHESS Program. A protocol for the study of ecological effects will be developed to provide a detailed accounting of the type, frequency, and density of biological effects information needed to monitor significant environmental stress impacts.

Although a large part of this work will be performed outside the direct RAPS framework, the monitoring data from the RAMS facility will be of direct use for ecological studies. In return, ecological studies can provide information on the uptake routes of pollutants, and thus guide the design of physical studies of the mechanisms and rates of pollutant removal processes.

Project 401--Precipitation Removal

Specific Objective--Determine the Rates of Pollutant Ingestion into Precipitation Systems and Removal from the Atmosphere.

Discussion--Although the importance of scavenging pollutants from the atmosphere by precipitation is often overstated on the basis of local before-and-after observations, the total impact of such scavenging constitutes the most effective process for the removal of pollutant gases and fine aerosols from the atmosphere on a worldwide scale. The importance of this process on lesser scales, such as that of RAPS, is poorly quantified; thus, the contribution of an urban region to alterations of the chemical constituents of precipitation is also poorly quantified. Studies of scavenging mechanisms over the past two decades have provided information about washout of inert aerosols (collection of the aerosol by falling precipitation elements), and some knowledge of rainout (incorporation of substances into developing precipitation elements) of substances that can act as condensation nuclei. The METROMEX program, an examination of the overall influence of the St. Louis area on precipitation modification, encompasses a study of the influence of an urban area on cloud physics, which includes measurements of cloud condensation and freezing nuclei. The effects of precipitation on atmospheric pollutants loadings is beyond the scope of METROMEX.

Method of Accomplishment--Concentrations of pollutants entering precipitation systems will be measured with aircraft instrumentation, and calculated from emission inventory data. Removal of pollutants from the overlying air by precipitation will be determined by analyses of rain water

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collected at numerous ground sampling sites.

The aircraft sampling plan will be tailored to the type of precipitation system being sampled: for convective systems, the air being ingested into the bases of developing clouds will be sampled, whereas for frontal systems, the air beneath the rain-generating level will be sampled. Consideration will be given to similar experiments during snow, although flight limitations may preclude aircraft measurements during these conditions. Initial focus will be on measurements of gaseous and particulate SO_x and NO_x species, but measurements of trace elements, particularly the heavy metals, may be added if the inventory and air quality data indicate a need.

Project Schedule--The first series of experimental measurements was conducted in conjunction with METROMEX participants during the summer of 1972. These measurements were on convective systems. Measurements on frontal systems are planned for fall, 1973, and spring, 1974, with additional measurement series added as analyses of collected data indicate a need.

PROJECT 402 -- SURFACE SCAVENGING OF POLLUTANTS

Specific Objective: Determine Rates of Removal, Fate, and Transformations of Gaseous and Particulate Pollutants by Surface Deposition and Natural Degradation Processes.

Discussion--The ability of airborne pollutants to soil and deteriorate materials as well as to damage and reduce the growth of crops and vegetation has been under study for a number of years. The chemical and physical forms, the biological transformations of the pollutants in nature, and the rates and mechanisms of removal have not been adequately investigated, however. Without sufficient knowledge of removal rates, the significance of surface assimilation in modifying the distribution of airborne pollutants cannot be assessed. The basic mechanisms of removal gravitational settling for sufficiently large particles and turbulent transport, impaction, Brownian diffusion, and molecular diffusion for successively smaller particle sizes through to gaseous substances-- are reasonably well understood, but when all the variables, such as geometric and chemical makeup of the surfaces, electrostatic and thermal forces that may act, solubilities and reactivities of pollutants, and possible biologically induced transformations, are combined, the lack of quantitative knowledge is understandable. The pollutant characterization studies described in Work Area 200 should provide a basis for delineation of physical removal processes for classes of pollutants, and thereby support the design of experimental measurements to quantify total physicobiological implications of surface removal rates and the transformation processes that occur in nature.

Method of Accomplishment--Sampling methods and procedures for an ecological effects monitoring system will be designed to provide experimental data describing the accumulation of airborne pollutants in or on various receptors for correlation with aerometric data from the monitoring network. Selection of sampling locations, elements to be sampled, and types of sample analyses will be strongly guided by the economic significance of pollution effects to be surveyed in project 603. This sampling will provide a measure of deposition integrated over periods of months or even years; provisions will be required in the sampling methodology to account for the influence of precipitation, both in adding pollutants to and removing them from the receptors. To determine the removal rates in more detail plans include special add-on experiments in which the deposition patterns of specific substances may be determined, e.g. particulate deposition on building surfaces or assimilation of gaseous pollutants in various growth zones of vegetation. Such experiments can also be used to determine bulk deposition rates using a mass balance approach in conjunction with release and sampling of inert gaseous tracers.

Project Schedule--Planning, including development of the ecological effects protocol, will be initiated in 1973. Collection of samples will be started late in 1974 or early 1975 after the monitoring network is in full operation. Special deposition experiments will be started in the summer of 1975.

SERIES 500 -- MATHEMATICAL SIMULATIONS

The primary, immediate objective of RAPS is to develop mathematical simulation of pollutants from both existent and hypothetical sources. Many approaches might be taken to attain this end. For calculating the dispersion of inert pollutants, statistical descriptions of the spatial distributions of pollutants (most commonly Gaussian in one or more dimensions) with corrections for source effects, depth of the mixing layer, etc., are currently the most successful. On the other hand, transformation and removal processes can be best simulated by variations of the flux-gradient relationship approach that employ eddy exchange coefficients to quantify such relationships. Boundary layer models, unlike the preceding simulations, must incorporate the equations of motion. The starting point for all simulation modeling of pollutants is the use of models of emissions that depend on engineering parameters that, in some cases, have no dependence on climatic conditions.

Because of this diversity of modeling methods for the various components that enter into the total pollutant modeling effort, along with the questionable validity of some of the component models, the focus of model effort will continue along diverse paths in the early stages of the study. This diverse approach permits the development of modeling standards by which the validity or accuracy of alternate methods that could better be used in a total simulation may be checked. Thus, in each of the process modeling areas, corresponding to the preceding four work area series, attention will first be devoted to characterizing each process in isolation-emissions, transformations, dispersion, and removal. However parallel effort will be undertaken to include the process simulations in a common simulation; indeed some such effort, although admittedly very crude at present, is already underway. Almost all simulation modeling planned for the early phases of the study represents a continuation of existing programs.

The first four projects listed below are counterparts of the four preceding work area series, and could have been included there; the primary distinction is that the preceding work areas require actual data, and are thus dependent on field measurements for their success, whereas simulations can precede observations and provide an experimental guide, or can follow the observations and use the observations as a guide.

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PROJECT 501 -- EMISSION MODELS

Specific Objective: Develop Mathematical Descriptions of the Emission Inventories for Use in Simulation Models.

Discussion-- Much of the inventory data to be obtained in Work Area 100 will be stored in the form of emission models, since they will consist of source data, emission factors, and temporal factors, together with a specified location and geometry for each source unit. These units may for example, describe a single stack, a section of expressway between interchanges, or an integral area containing a number of residential buildings. To serve as input for simulation models of pollutant concentrations in which all sources of a given pollutant must be jointly considered, additional manipulation of these source units is required to provide emission values of each pollutant for a configuration of unit sources appropriate for a particular model. In the eventual testing of control strategies, synthetic source distribution and emission factors will be employed; thus, the procedure developed for manipulating the inventory data must be amenable to the introduction of such synthetic data.

Method of Accomplishment -- After the basic format of the emission inventory is determined, techniques will be devised to convert data to the appropriate input format for pollutant models. The first application will be the evaluation of existing models (Project 505). As transformation models and integrated simulation models requiring emission data are formulated, formats will be generated to provide the necessary input data.

Project Schedule--Work will be initiated late in 1973, after the basic inventory format is essentially determined. Conversion of present data to permit the evaluation of existing models should be finished in about

6 months, so that these evaluations can be started as soon as sufficient emission and basic inventory data are obtained. Specification or input data for simulations to be developed will continue during the course of the study.

PROJECT 502 -- TRANSFORMATION MODELS

Specific Objective: Quantify Atmospheric Transformation Processes and Rates.

Discussion--To incorporate the role of atmospheric transformations into integrated mathematical simulation models, numerical analogs of these transformation processes must be developed. The precision required of these analogs, expressed in terms of net sensitivity of calculated concentrations to variations of the reaction rates, is not well defined for most reactions. Accuracy is dependent not only on the rates *per se*, but also on the order and reversibility of the reactions and the influence of admixtures of pollutant substances other than those altered by the reactions. The kinetics of photochemical reactions have been intensively studied, and a number of reaction steps have been identified and quantified by rate. A considerable detail of both qualitative and quantitative work remains to be done before analog simulations of such reactions can be successfully developed. The simulation of aerosol formation is far less advanced: little knowledge of even a qualitative nature has been developed. Due in part to the different levels of understanding of reaction mechanisms, mathematical analogs of the reactions used in pollutant concentration simulations may be expected to differ considerably in the exactness of the analogies. In addition, simplification of the analogs, e.g., lumped reactions, may be acceptable if reaction intermediates are not of concern.

Method of Accomplishment--Extensive field measurements, described in various Work Area 200 projects, will supply a continuing input of new data on transformation processes during the study. Model studies initiated under preexistent programs will be continued and expanded to incorporate these new data as they come available. Simplified mathematical analogs in forms suitable for incorporation into integrated mathematical models will be developed and validated using more exact transformation models, if available, as test data. Analogs will also be developed for transformations that can be shown to be of importance through sensitivity analyses, but for which knowledge of the processes involved may be much more limited; of necessity, such analogs will be subject to empirical adjustment within the context of the integrated model(s) of which they are constituent parts.

Project Schedule--Contract work under existing EPA programs will be continued so that transformation processes and rates important in photochemical reactions can be better defined. Results of St. Louis field measurements will become available late in 1973. Mathematical analogs can then be developed as experimental results are derived.

PROJECT 503 -- ATMOSPHERIC STRUCTURE MODELS

Specific Objective: Develop Regional Scale Models of the Planetary Boundary Layer.

Discussion--Mathematical descriptions of atmospheric dispersion, air flow, and associated turbulence are required for use in integrated simulation models of pollutant concentrations. Because of the lack of actual observations sufficient to define the air structure throughout the regional volume in which the dispersion occurs, present simulation models utilize assumptions concerning the dispersion that are too simplified under many circumstances. Models that incorporate all the physical processes determining the structure of the boundary layer, inlcuding its spatial and temporal variations, are possible in principle, but even the formulation of such models has not been attempted. Rough estimates of the computer capacity and running time required, if such a formulation were available, indicate that a complete simulation would, at present, be impractical to attempt. The basic difficulty is that the (time averaged) mean flow, the turbulence, the turbulent fluxes, and the radiant energy fluxes are interdependent in the real atmosphere, and must be so treated in any computer simulation. Because of the magnitude of the total problem, even the most ambitious simulations treat only parts of the overall problem. In addition, and in large part because of the overall complexity of the problem, atmospheric modeling on the scale of an urban region has only recently been attempted; a wide gap still exists between scaled-down numerical weather prediction calculations that yield information primarily on the mean flow, and scaled-up diffusion calculations in which the mean flow is taken as known. So far only the most elementary calculations have been performed in which coupling between parameters has been attempted, e.g. between pollutant concentrations and radiant flux divergence or between temperature differences and heat fluxes.

Method of Accomplishment--Formulations currently under development as well as existing formulations that are intended to describe boundary layer flow, turbulence, and vertical fluxes will be reviewed for possible direct application in limited circumstances and for possible additional development or combination with other formulations. The most successful approach will probably consist of a nesting of scales, proceeding down in both grid size and areal extent from mesoscale adaptations of numerical weather prediction calculations, through urban-scale perturbations of the mean flow induced by the varying heat and momentum fluxes, to the local eddy diffusion. Some up-scale feedback will be required to achieve consistency between the mean flow and the turbulence it is likely that the radiant energy flux divergence will have a significant influence on the mean thermal structure and its urban-scale variations, particularly with light overall winds. The measurements planned under Series 300 will furnish an extensive data set with which model calculations can be validated.

Project Schedule--Existing models will be cataloged and reviewed, and adaption and development of new models will be initialed in 1973. The initial focus will be on partial models, e.g. mean flow models, radiation transfer models, etc. As field data become available, these partial models can be checked, and the synthesis of a complete model will be undertaken.

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PROJECT 504 -- REMOVAL PROCESS MODEL

Specific Objective: Quantify the Removal Rates of Gaseous and Particulate Pollutants.

Discussion--In most existing dispersion formulations, removal of pollutants from the atmosphere is ignored. The reason is twofold; first, to include removal, whether through washout by precipitation or deposition on surfaces, adds a great deal of mathematical complication of dubious value to the calculations; and second, because many calculations are made to estimate the maximum ground-level airborne concentration that may be expected to occur, to ignore the removal provides some safety margin in the calculations. To adequately describe the ecologic and economic effect of air pollution, however, the rate of pollutant uptake, not just the airborne concentrations, must be quantified for the relevant exposure duration. Because actual measurements will provide only the sketchiest of temporal and spatial coverage, mathematical relationships between the overlying airborne concentrations and meteorological factors on the one hand, and the surface type and rate of pollutant uptake on the other, must be developed. In addition, these relationships must be extended so that the depletion of airborne concentrations can be adequately simulated and incorporated into integrated pollutant simulation models.

Method of Accomplishment--Existing mathematical relationships and experimental data on removal of airborne materials will be reviewed concurrently with development of the protocol described in the Series 400 introduction. Formulations relating airborne concentrations of gaseous and particulate materials to deposition on surfaces will be derived, and tested by the experimental data that becomes available during the course of the study. The degree of complexity required, e.g., deposition in various height zones of vegetation versus simplified gross deposition on the entire plant surface, is unknown at present. Experimental data concerning the pollutant content in precipitation samples will be generalized to the maximum extent possible by using models relating the overlying, integrated pollutant loading to precipitation rates and scavenging efficiencies; these largely empirical relationships will be applicable only for longer time intervals, on the order of a month. Sensitivity analyses will be performed to determine the conditions under which surface deposition should be considered as influencing the concentrations of airborne pollutants. Deposition models will be adapted for use in integrated pollutant simulation models as the need is indicated by the sensitivity analyses.

Project Schedule--Formulation of deposition models will begin in 1973 to guide the design for collection of field data and performance of experiments, which will begin about the following year. Sensitivity analyses will be made concurrently with formulation of the deposition models. Emperical precipitation scavenging models will require at least crude dispersion models, together with emission inventory data; work will be initiated in this area when sufficient inventory and network data are available.

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PROJECT 505 -- EVALUATION OF EXISTING POLLUTANT SIMULATION MODELS

Specific Objective: Assess the Validity and Applicability of Current Multiple Source Air Quality Simulations

Discussion--A number of multiple-source dispersion models have been developed by different groups during the past decade, but most have been applied to the so-called inert pollutants. Transformations have been neglected or, at best, treated in the calculations as obeying a simple exponential decay law. Detailed intercomparisons between these models have not been made, primarily because the data bases on which the models were developed differ from one to another. Additionally, uncertainities in all three components of these data bases - emissions, including source geometry, atmospheric dispersion parameters, and air sampling data--are sufficient to preclude a true verification even if transformations of the pollutant being simulated could in reality be ignored. With the data base expected as the study proceeds, however, it should be possible, by analyses of residual errors, to empirically identify some of the major sources of error and thus guide the design both of field experiments and of mathematical simulations to better describe the processes associated with these errors.

Because no models exist, evaluation of reactive pollutant simulation models is specifically excluded. Such models will generally be far more complex than the existing generation of models. For any meaningful manipulation of control strategy formulations, however, the present simulation models are already complex enough, and may serve a useful role for some time to come if their limitations can be specified.

Method of Accomplishment --A limited set of models, perhaps three, will be chosen for detailed evaluation using the RAPS data base. These models will range from the very simple, in terms of temporal and spatial resolution and associated computation requirements, to the reasonably complex. Four or more of the routinely measured pollutants should be simulated -- perhaps fine particulate, SO_2, CO, and either total or non-methane hydrocarbon, since among other reasons, one or more models for each presently exist. Analyses of the errors should include attempts to identify the source of the error. For example, a consistent undercalculation that varies temporally but not spatially would imply that a varying background concentration was not included; an overcalculation by a constant ratio would imply that the inventory values are low, but an overcalculation in which the ratio increases with distance from the major sources could imply a gradual transformations, the existence of deposition, or a more complex dispersion pattern than first assumed. Some errors will be amenable to correction by relatively simple adjustments, but errors that cannot be corrected may limit the applicability of a particular model.

Project Schedule -Candidate simulation models will be selected and adapted to the RAPS data base so that tests may be started as soon as an adequate volume of sampling data from the monitoring network becomes available. Work on this project should be completed by the end of 1975.

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PROJECT 506 -- INTEGRATED SIMULATION MODELS

Specific Objective: Develop and Validate Air Quality Simulation Models Incorporating All Significant Source and Atmospheric Parameters.

Discussion--Assorted models that satisfy a variety of requirements must be developed in a form and complexity that will accomplish the primary objective of RAPS. For instance, a real time model, ie., one capable of simulating the main features of pollutant distributions over a limited temporal and spatial domain, must include specific values for parameters that, in a model intended to provide only climatological data, can be handled much more easily through a statistical approach. Again, the relative importance of various processes, and hence the appropriate simulation techniques, will depend on the travel time from source to receptor. For example, details of the turbulent structure that are of primary importance at short travel times become relatively unimportant at a regional scale, where the gross mean atmospheric structure is the main determinant of dispersion. Transformation processes requiring complex simulation techniques for shorter travel times may be simplified for longer travel times; deposition processes become more important, however, and require a more complete simulation as travel time increases. Given the full range of complexity of all source and atmospheric variables, it probably will not be feasible to develop one complete model that can be simplified to form a set of models for various applications; instead, a set of models that can be validated over their ranges of application appears to be a more promising approach.

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Method of Accomplishment--As simulations are developed for describing the several processes that determine the concentrations of pollutants (Projects 501-through 504), methods will be developed to incorporate these process simulations into comprehensive simulations for specific applications. Concurrently, the applications of comprehensive models will require more specific definition; this may be accomplished by a cost-benefit analysis, but will be a continuing process, since the output of feasible simulations will change continously.

Project Schedule--Initial development of comprehensive models will begin in 1973; this development, together with updating of the model applications will continue for the duration of the study.

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WORK AREA 600 -- CONTROL ECONOMICS

Major emphasis in the study on control economics is the development of modeling systems that will produce reasonably accurate information relating the costs of air pollution controls to the benefits to be realized from improved levels of air quality.

Capital investment and costs of control technology are obvious considerations that influence control economics; less apparent components include the geographic distribution of people relative to pollution sources, the distribution of income and social characteristics among community populations, and the existence of factors other than air pollution that influence community health. In gathering these kinds of information, feed-back may effect changes in the design of the studies of physical models. Benefits of improved air quality to human health and productivity, social activity, land use, animals, crops, and materials will be studied.

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PROJECT 601 -- COSTS TO HUMAN HEALTH

Specific Objective: Quantify the relationship between health and air pollution.

Discussion--Because the objective of Project 601 closely resembles that of the EPA CHESS program, CHESS information will be incorporated by this project. Examination of the relationship between human health and air pollution is difficult for a number of reasons. Except in rare severe episodes, the effects of air pollution on health accumulate over long periods of time, during which individuals move between environments and changes occur in local levels of specific pollutants. Health records on individuals are usually incomplete or difficult to obtain. Measurements of air quality levels are seldom available for each of the local areas in which any individual lives, works, travels, pursues recreational and other activities. Measurements are especially unavailable for pollutant levels inside buildings and vehicles where people spend much of their time. The results of Project 601 therefore, are likely to be somewhat limited, but are still expected to provide a valuable input to the analysis of the benefits of controls.

Method of Accomplishment--CHESS and CHESS-type survey panel procedures and questionnaires will provide health and socioeconomic data concerning many individuals in the St. Louis metropolitan area. The degree of exposure for these individuals to a variety of air pollutants will be obtained from the CHESS and RAPS air quality monitoring networks or from diffusion models. These data will then be statistically analyzed to estimate the relationships between health effects and air pollution exposure. Dollar quantification of the estimated air pollution health effects will be carried out using health costs data. If significant damage

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(cost) relationships are found, they will be compared with corresponding control costs to test the cost/benefit adequacy of pollution control standards.

Project Schedule--Health studies will begin in mid 1973.

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PROJECT 602--CHANGES TO HUMAN ACTIVITIES AND LAND USE

Specific Objective: Estimate the effect of air pollution on human social behavior.

Discussion--People tend to modify life styles and other aspects of behavior in response to their atmospheric environment: the level of air pollution is one factor in that environment. A wage earner, because of his employment skills, may be forced to move into a community that is subject to petroleum processing fumes, but another may be able to move to a rural area to avoid air pollution. Cost factors include the expense of commuting and the cost of housing. An individual who chooses to live in a polluted area to avoid commuting costs may be faced with the cost of air filters or purifiers for his home. He may also change his recreation pattern from home gardening to woodworking in his basement, as an example. As thousands of residents are effected by air quality, such costs may add up to major changes in community economy and in the failures or relocations of entire industries.

As with the influence of pollution on health, some of these social effects are difficult to identify and measure, especially in terms of the contribution from air pollution as opposed to other factors. Community behavior is rarely so stable that it can be changed in an easily measurable way by a single environmental influence.

Method of Accomplishment--Neighborhood surveys will be used to determine the damages (costs), other than direct health costs that residents incur in order to avoid or live with air pollution or to modify their social behavior. Such costs will include, for example, extra housing moves, pollution removal devices, changes in social activities and changes in recreation. The levels of pollution involved will be mapped from RAPS data and using

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RAPS models.

Project Schedule--Some of this information will be included in surveys of human health. Surveys of damages (costs) will be contracted beginning in late 1973, and surveys of other changes in social behavior will follow probably in 1975. Land use surveys are also planned for the latter portion of the RAPS program.

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PROJECT 603 -- COSTS TO ANIMALS, VEGETATION, MATERIALS

Specific Objective: Estimate the cost of air pollution with respect to man's resources and tools.

Discussion--Among the factors that are suspected of having a significant input to the total cost of air pollution are the loss of foliage and forests, modification of precipitation chemistry and resulting damage (or fertilization) to vegetation, animal and livestock health, and corrosion of tools, materials and buildings. These and other effects have been the subject of past field and laboratory studies that will not be repeated by RAPS. The methods that have been used to assess the damage (cost) bear further investigation, however.

Method of Accomplishment--Surveys of personnel of agricultural schools and farm-related businesses, veterinarians, park administrators, nurserymen and farmers will be used to determine the economic losses caused by air pollution effects on vegetation and livestock. Sample surveys of selected industries will be used to determine materials losses. RAPS air quality data and modeling techniques will be used to evaluate the air quality levels involved.

Project Schedule--These surveys are planned to be done by contract beginning in 1973 and continuing through 1976.

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PROJECT 604 -- COSTS OF MEETING CONTROL LEVELS

Specific Objective: Provide the information about the costs of control strategies needed to model cost benefit relationships.

Discussion--The first diffusion models to be tested in RAPS will probably not meet the requirements for accuracy needed for meaningful evaluations of the results of control strategy alternatives. Consequently, more detailed designs and studies must wait on demonstrations of the validity of these models. In earlier stages of RAPS, however, the costs to government and industry and to the general public of implementing controls will be acquired for use in subsequent model tests. This project will include the application of RAPS models to the St. Louis area for testing of control strategy and economic benefit inputs.

Method of Accomplishment--Process and activity-related control cost functions will be developed for specific pollutants and specific sources. Alternative control strategies will be specified. Using these inputs, the best available air quality simulation models will be employed to check the applicability and utility of the cost information. This process will be repeated with improved simulation models for the St. Louis situations and strategies. Trial evaluations of the effect of implementation processes on the regional economy will be made, and the benefit functions will be added in an experimental cost-benefit analysis of the St. Louis region.

Project Schedule--Initial development of the economic cost model and the emission control cost data base began in 1972. Work on control cost functions will continue in 1973 with preliminary model checkouts in late 1974. Final trials of the economic data in the models will extend through the remainder of the study.

June, 1974
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REGIONAL AIR POLLUTION STUDY

FINAL REPORT

THE REGIONAL AIR POLLUTION STUDY PROGRAM

Task Order No. 9

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FORWARD

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INTRODUCTION

This report presents an integrated program for the conduct of the St. Louis Regional Air Pollution Study (RAPS). Its purpose is to provide the Environmental Protection Agency with an aid to (a) the effective management of the RAPS, (b) the implementation of a systematic and logical direction and coordination of the laboratory and field programs of the RAPS, and (c) assurance of flexibility in evolution of the experimental program of the RAPS.

ST. LOUIS REGIONAL AIR POLLUTION STUDY (RAPS)

The St. Louis Regional Air Pollution Study is the most ambitious study of its type ever attempted. The three major objectives sought of the RAPS are:

1. Develop, evaluate and validate air quality simulation models (AQSM) on a regional scale covering urban/rural stationary and mobile sources.
2. Develop, evaluate and validate models of local-scale phenomena which complement regional-scale models.
3. Create a comprehensive, accurate and readily retrievable data base for all criteria pollutants and selected non-criteria pollutants to use in evaluating future air quality simulation models and effects models.

As currently envisaged, a spectrum of regional air quality simulation models will be produced for all criteria pollutants, plus sulfates, nitrates and selected aerosols (e.g., fine particles), which have been validated against St. Louis field data.

This spectrum will incorporate subsidiary meteorological and chemical mathematical models which are needed as inputs to the AQSM and are capable of predicting analytically the atmospheric concentrations of pollutants as functions of pollutant levels, urban structure and heat emissions.

Within these objectives, the highest priority will be given to sulfur oxides. The rationale behind choosing these materials for focus at highest priority is that acid sulfate aerosols, which originate principally from sulfur dioxide oxidation, adversely affect human health, vegetation, materials and visibility.

A RAPS PLAN

The experimental plan described here focuses attention on the RAPS objectives. The specific purposes of the plan include:

1. Development and organization of existing information of the RAPS plans, ideas and concepts.
2. Establishment of a framework for the scheduling and control of the RAPS operations, including measurements and to a lesser extent modeling and data management requirements.
3. Provision for focusing the mainstream of the RAPS effort while allowing for incorporation of new experiments and new knowledge to be accounted for in establishing acceptable air quality models.

To achieve these goals, a dynamic procedure was chosen (after discussion with EPA/RAPS management) that can be used to review the progress of the project with maximum flexibility. but with necessary conformity to scheduling, utilization of resources, reporting procedures, etc.

REPORT ORGANIZATION

An overview of RAPS is presented via a discussion of the five basic elements of activity within the RAPS: 1) Model Development and Evaluation, 2) Emission Inventories, 3) Aerometric Measurements, 4) Data Management and 5) Program Management.

The essential role of each activity is then established by illustrating the logical relationship between all RAPS technical elements. Specifically, for all technical elements discussed their role in model development and evaluation is presented schematically in terms of the parameter(s) measured and model requirements.

Procedures for reviewing the various pieces of the RAPS are discussed and specific recommendations made. All of these elements are then brought together in time via a Master Milestone Chart of the entire program. Finally, the use of the procedures recommended is demonstrated for the summer '74 field expeditionary program plan.

1 RAPS STRUCTURAL PLAN

The past experience in comparing air quality simulation models with observations has provided only limited knowledge of the model sensitivity to key elements, particularly those which define the meteorological processes and the atmospheric chemistry and transformation processes involved. In addition, there has been a general absense of simultaneous measurement and data collection for defining these processes. In this respect, the development of air quality models has suffered from the lack of simultaneous measurements of parameters needed for model validation. Qualitatively, it is clear that one can expect that the key features for satisfactory modeling must center around the accuracy of:

- pollutant measurement
- the emission inventory,
- the characterization of meteorology on a maximum scale of tens of kilometers,
- the material balance of the pollutant species in question.

Thus, the RAPS must address itself to establishing an improved knowledge base for these elements; their relationship to AQSM output must reflect the regulatory requirements of the 1970 Clean Air Act.

Although the development of local scale models is not a major objective of RAPS, such models would indeed complement the regional scale models being produced. The aerometric measurements gathered in the St. Louis bi-state area will be added utility for more limited-scale studies that are undertaken through other programs.

PROGRAM MANAGEMENT

The implementation of the proposed plan requires either the existence or establishment of program management. This is a vitally important element of the RAPS structure. This effort must be successful in planning, organizing, directing and controlling the resources, skills and knowledge to complete the RAPS (by 30 June 1977) in an orderly manner and meet established objectives in time, budget and technical results.

The plan proposed herein is intended to be consistent with our current understanding of the EPA/RAPS program management. In Figure 1 the principal members of this management team are given along with the geographical location.

Program Element Director (Dr. J. Thompson, RTP)	-	responsible for overall program management
Field Director (Mr. F. Schiermeier (Acting))	-	responsible for all aspects of St. Louis field operations
Research Coordinator (Dr. F. Pooler, RTP)	-	responsible for providing scientific liaison between the participating EPA Divisions to insure that all RAPS research activities are consistent with RAPS purposes; identifies program inadequacies; with NERC program managers the needed budgeting and planning information of EPA headquarters is furnished.
Data Manager (Mr. R. Browning, RTP)	-	responsible for establishing and maintaining a data management system which converts participants' data requirements into design and operation specifications for the data processing formatting, storage and retrieval systems; provides assistance to RAPS participants in obtaining and interpreting needed data from the RAPS data bank.
Manager for Research Operations (Mr. S. Kopczynski, St. Louis)	-	responsible for monitoring contract operations in matters affecting the scientific applicability of the data; assists EPA/RAPS participants in arranging for and carring out out field expeditionary data acquisition; ensures data applicability of special expeditionary measurements and monitors data quality.
Facility Manager (Mr. J. Reagan, St. Louis)	-	responsible for RAMS network operations and maintenance; monitors data applicability and quality of special expeditionary instrumentation; responsible for St. Louis data processing, storage and retrieval activity.
Field Operations Coordinator (Mr. F. Schiermeier, St. Louis)	-	responsible for planning and execution of EPA/RAPS field expeditionary data acquisition; coordinates EPA/RAPS field data acquisition activities in the St. Louis area with those of other agencies; provides meteorological services in support of RAPS field activities.
Administrative Assistant (To be filled, St. Louis)	-	responsible for monitoring contractual programs and the maintenance of all fiscal records in St. Louis.

Figure 1. RAPS Management Summary

TECHNICAL ELEMENTS OF THE RAPS

The RAPS can be structured in different ways to implement programs for achieving its objectives. We have chosen to structure the program as indicated in Figure 2 with an operational classification in terms of four basic elements: a) model development and evaluation, b) emissions inventories, c) aerometric measurements, and d) data management.The data management function serves as a bridge between the model development and the emissions and aerometric measurements efforts to insure the interaction and feedback between field oriented activities and data utilization or interpretative activities (a project breakdown structure with significantly more detail may be found in Appendix A).

The structure and content of the proposed plan benefitted measurably from the RAPS No. 1 Study Plan even though when its content is compared with Figure 2 it may not be readily apparent. As will be evident later, virtually every component of the Study Plan remains.

In the sections which follow, the roles of each of these principal elements will be discussed.

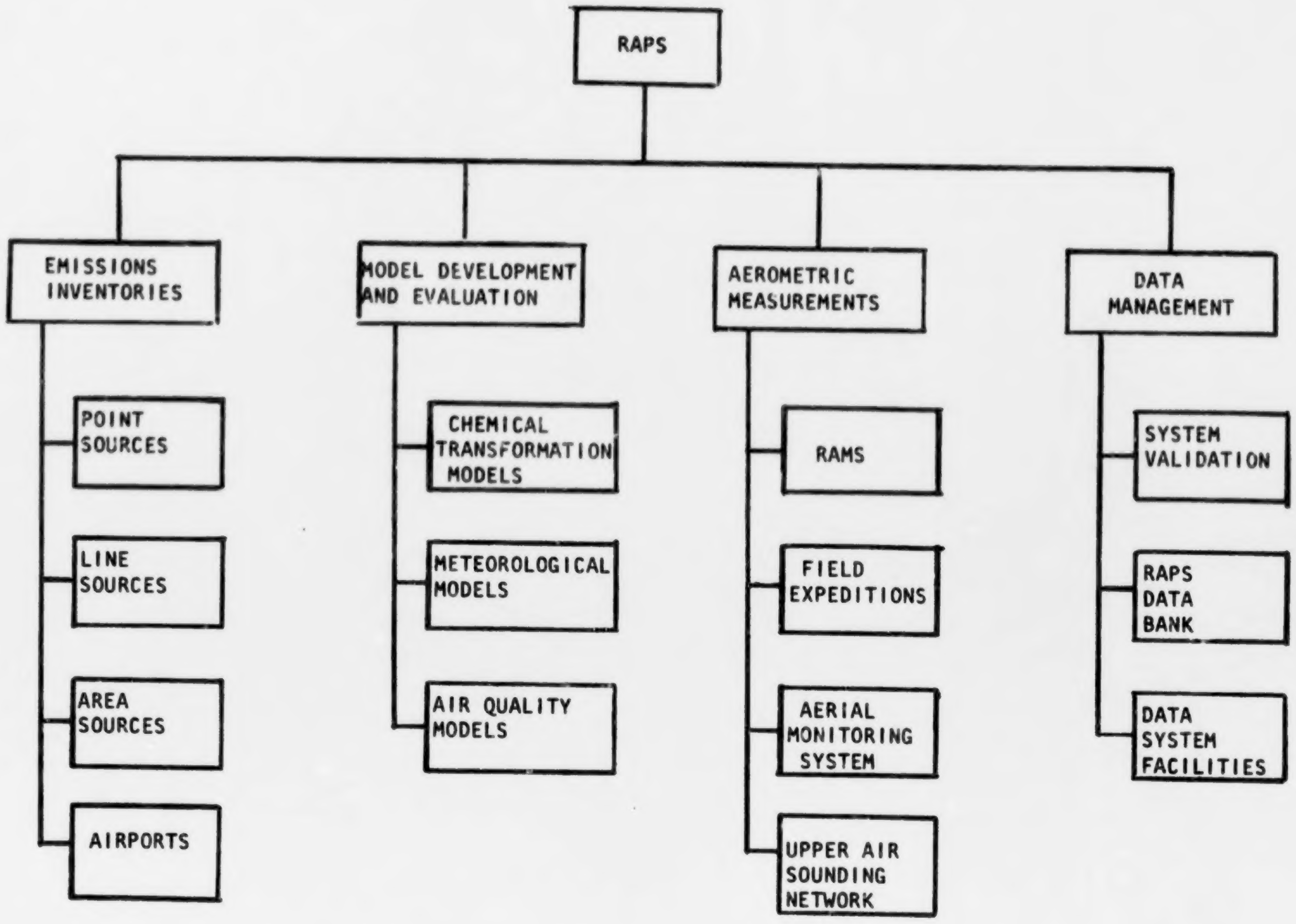
RAPS
EMISSIONS INVENTORIES
POINT SOURCES
LINE SOURCES
AREA SOURCES
AIRPORTS
MODEL DEVELOPMENT AND EVALUATION
CHEMICAL TRANSFORMATION MODELS
METEOROLOGICAL MODELS
AIR QUALITY MODELS
AEROMETRIC MEASUREMENTS
RAMS
FIELD EXPEDITIONS
AERIAL MONITORING SYSTEM
UPPER AIR SOUNDING NETWORK
DATA MANAGEMENT
SYSTEM VALIDATION
RAPS DATA BANK
DATA SYSTEM FACILITIES

Figure 2. Principal Elements of Regional Air Pollution Study (RAPS)

MODEL DEVELOPMENT AND EVALUATION

In the plan proposed, the model development and evaluation efforts take a leading and crucial position. Of the variety of models to evolve under the RAPS framework, the initial effort will be concentrated on the emissions and aerometric models. The development of the ecological and economic models are not within the scope of this report. Although these depend on the emission and aerometric models, they can be derived partially in parallel.

Objectives of Model Development and Evaluation Program

The objectives of the RAPS model development and evaluation activity are:

1. Establish criteria for evaluation of air quality simulation models consistent with RAPS objectives.
2. Establish a protocol for the quantitative validation and acceptance of each model or sub-increment within the context of the present ambient air quality standards.
3. Quantitatively test and evaluate existing models or submodels for the applicability to the regional air quality specification.
4. Identify the critical elements and limitations (quantitatively whenever possible) of the models that require further improvement to meet acceptable levels of model performance.

A Plan for Model Development and Evaluation

The importance of technical leadership by the model development and evaluation team cannot be overstated. A schedule for the overall modeling activity is given in Figure 3. Leadership by the modelers is established through periodic and formal recommendations reports. As a minimum, these reports are to be concerned with improvements in aerometric measurement, emission inventories and data management operations and procedures. As Figure 3 shows, two full years for model evaluation are available following the conversion and implementation of all models for the St. Louis Air Quality Control Region (AQCR).

BROAD SCHEDULE FOR MODELING ACTIVITY

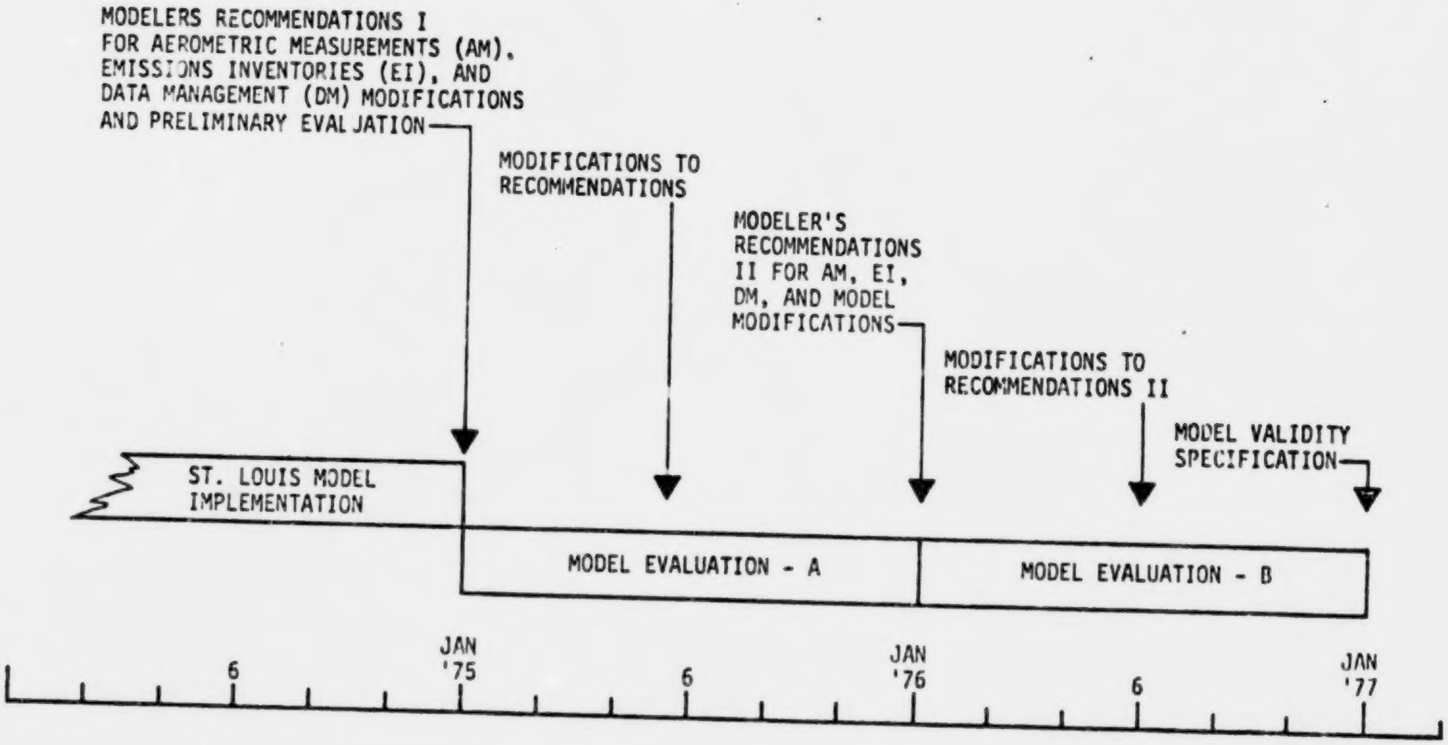

Figure 3. Broad Schedule for Model Development and Evaluation Program

During this period, nearly two full years of data will be accessible.

Figure 4 presents a relatively detailed flow chart for carrying out the modeling activity through the first full year of evaluation (up to January 1976) for each and any model applicable to the RAPS objectives.* The second year of evaluation is similar to the first year of evaluation and, along with the full modeling effort, is presented in the PERT NETWORK (Figure B.1 in Appendix B).

Estimates of time for each activity in the network (represented by the horizonal lines in Figure B.1) are given only for the period following January 1, 1975. The status of current models with respect to conversion and implementation to the St. Louis AQCR is strongly determined by the particular model being considered.

The flow diagram in Figure 4 is, in principle, applicable to each model. Thus, the progress of the models considered applicable to the RAPS objectives can be followed by reference to it. In implementing this plan, it is therefore recommended that the status of each model under consideration be assessed according to this chart. With this information a more detailed schedule would then be established and the network in Figure B.1 also implemented.

Finally, the importance of establishing evaluation criteria in the very early stages of the model development program cannot be overemphasized. It is recognized that these may change in the course of the RAPS, but the direction these criteria will give to the modeling effort and therefore to the entire RAPS is paramount.

Recommendations

In summary therefore, the following recommendations are made:

- The leading role of the modelers be established and implemented.

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* A relatively complete list is in Figure A.1 in the Project Breakdown Structure

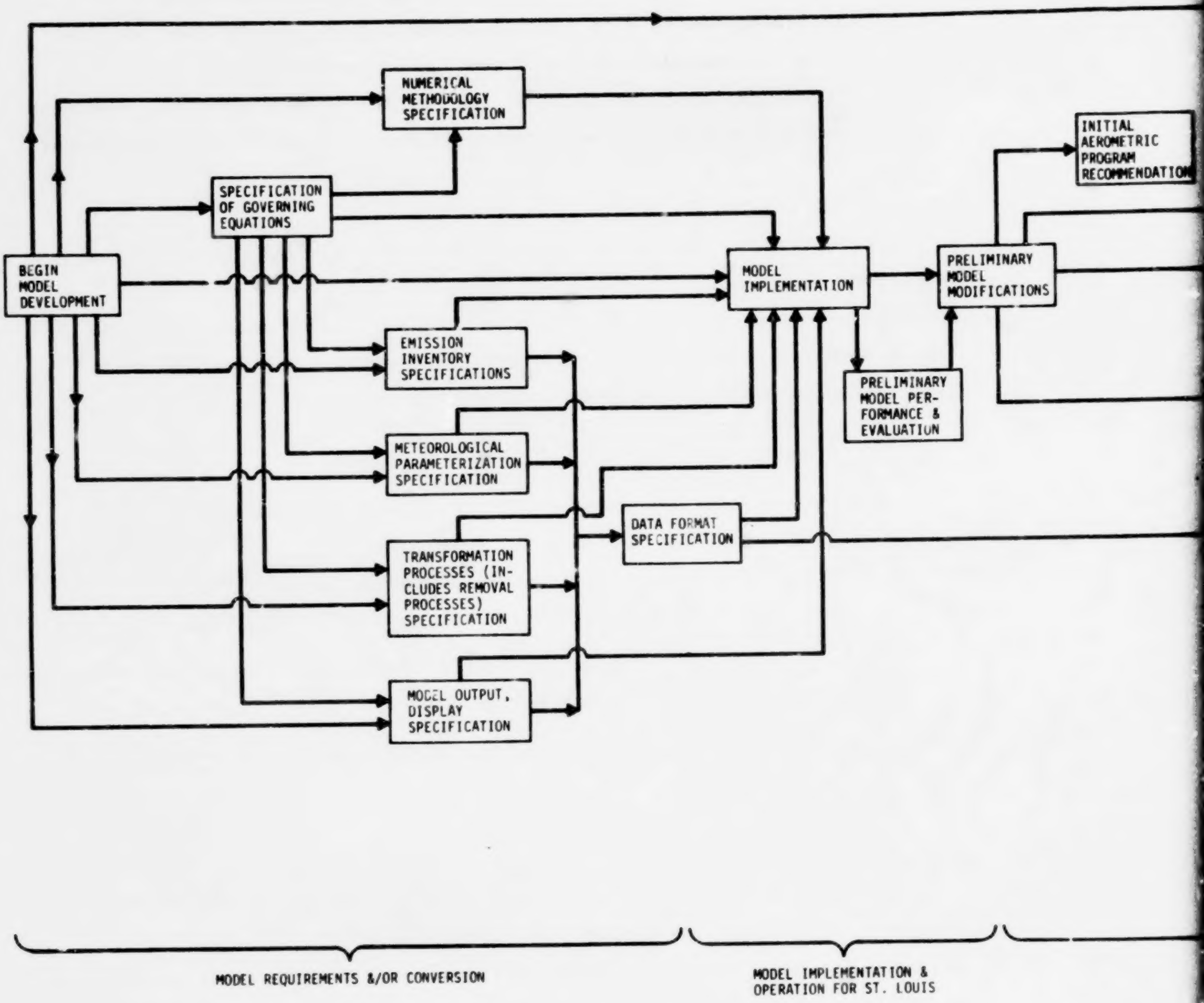
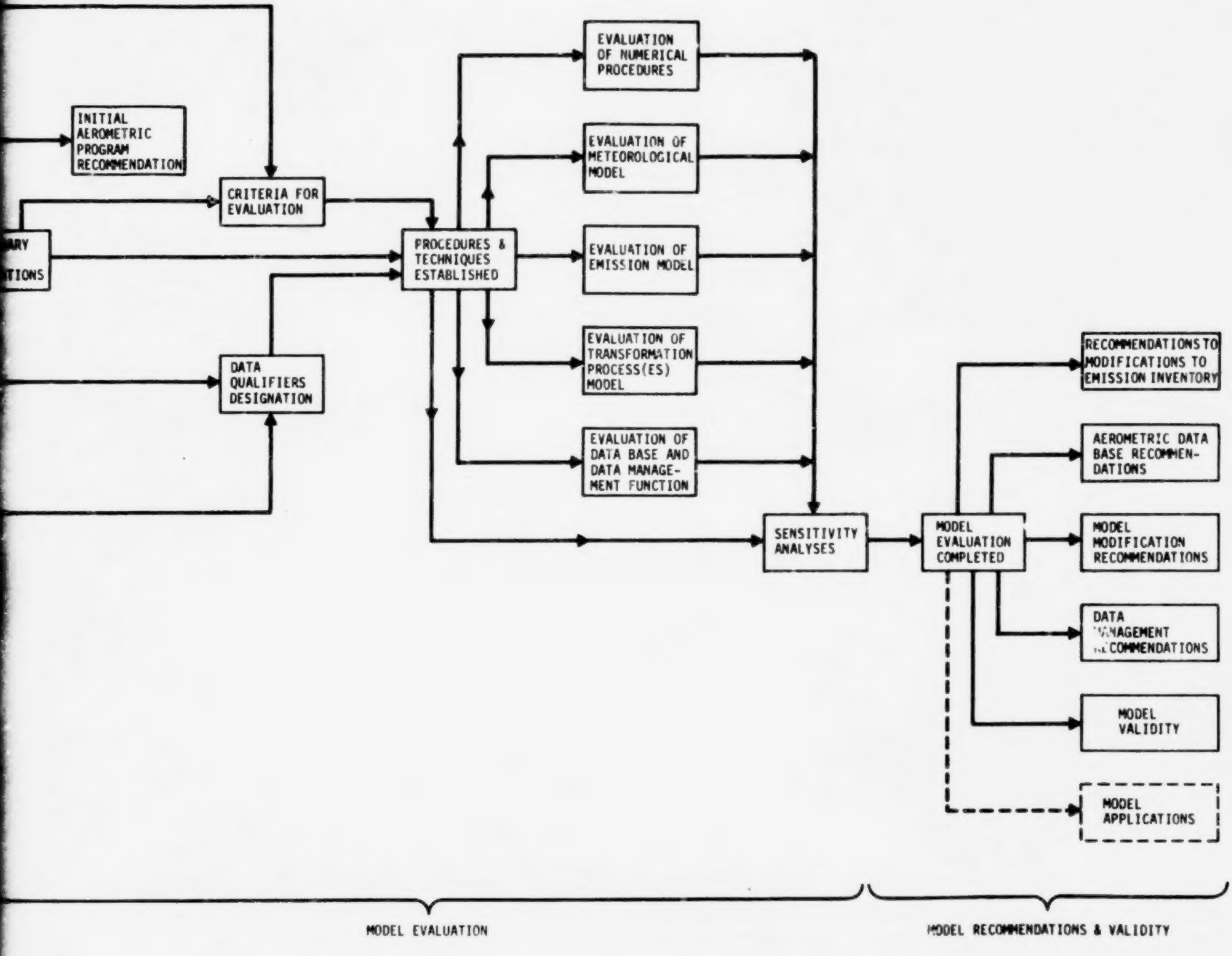

NUMERICAL METHODOLOGY SPECIFICATION
SPECIFICATION OF GOVERNING EQUATIONS
BEGIN MODEL DEVELOPMENT
MODEL IMPLEMENTATION
PRELIMINARY MODEL MODIFICATIONS
INITIAL AEROMETRIC PROGRAM RECOMMENDATION
PRELIMINARY MODEL PER- FORMANCE & EVALUATION
EMISSION INVENTORY SPECIFICATIONS
METEOROLOGICAL PARAMETERIZATION SPECIFICATION
DATA FORMAT SPECIFICATION
TRANSFORMATION PROCESSES (IN- CLUDES REMOVAL PROCESSES) SPECIFICATION
MODEL OUTPUT, DISPLAY SPECIFICATION
MODEL REQUIREMENTS &/OR CONVERSION
MODEL IMPLEMENTATION & OPERATION FOR ST. LOUIS

Figure 4. Flow Chart of Model Developme


INITIAL AEROMETRIC PROGRAM RECOMMENDATION
ARY
TIONS
CRITERIA FOR EVALUATION
DATA QUALIFIERS DESIGNATION
PROCEDURES & TECHNIQUES ESTABLISHED
EVALUATION OF NUMERICAL PROCEDURES
EVALUATION OF METEOROLOGICAL MODEL
EVALUATION OF EMISSION MODEL
EVALUATION OF TRANSFORMATION PROCESS(ES) MODEL
EVALUATION OF DATA BASE AND DATA MANAGEMENT FUNCTION
SENSITIVITY ANALYSES
MODEL EVALUATION COMPLETED
RECOMMENDATIONS TO MODIFICATIONS TO EMISSION INVENTORY
AEROMETRIC DATA BASE RECOMMENDATIONS
MODEL MODIFICATION RECOMMENDATIONS
DATA MANAGEMENT RECOMMENDATIONS
MODEL VALIDITY
MODEL APPLICATIONS
MODEL EVALUATION
MODEL RECOMMENDATIONS & VALIDITY

odel Development and Model Evaluation

- Model evaluation (and validation) criteria be established on a continuing basis, with initial concepts available by June 1, 1974.
- Annual recommendations, with semi-annual modifications (to those recommendations), be given to the aerometric measurements, emissions inventories and data management efforts through EPA/RAPS management.

EMISSION INVENTORIES

The realization of the RAPS objectives can occur only if effective assessment of emissions from air-polluting sources is made. Moreover, success in this element alone will go a long way toward determining the extent to which estimation of pollutant emissions can be generalized for application to different geographical situations.

Objectives of Emission Inventory Program

The objectives of the emission inventory activities are:

1. To establish the methodology, data collection, data handling, and data validation systems necessary for support of the model development and evaluation effort.
2. To provide the quantitative emissions data (with estimates of reliability) necessary for model validation.
3. To identify the critical factors which impact model evaluation and validation.

A Plan for Emissions Inventories

The National Air Data Branch, MDAD, OAQPS, OAWM is the EPA organization charged with the lead responsibility for RAPS emission inventory, emission factor, and emission model efforts. A plan for carrying out this emission activity at the time of this writing is well underway. Dr. Hammerle and his staff have implemented a program whose broad scheduling features are given in Figure 5. As shown, the program breaks down into five basic areas: 1) emission inventory

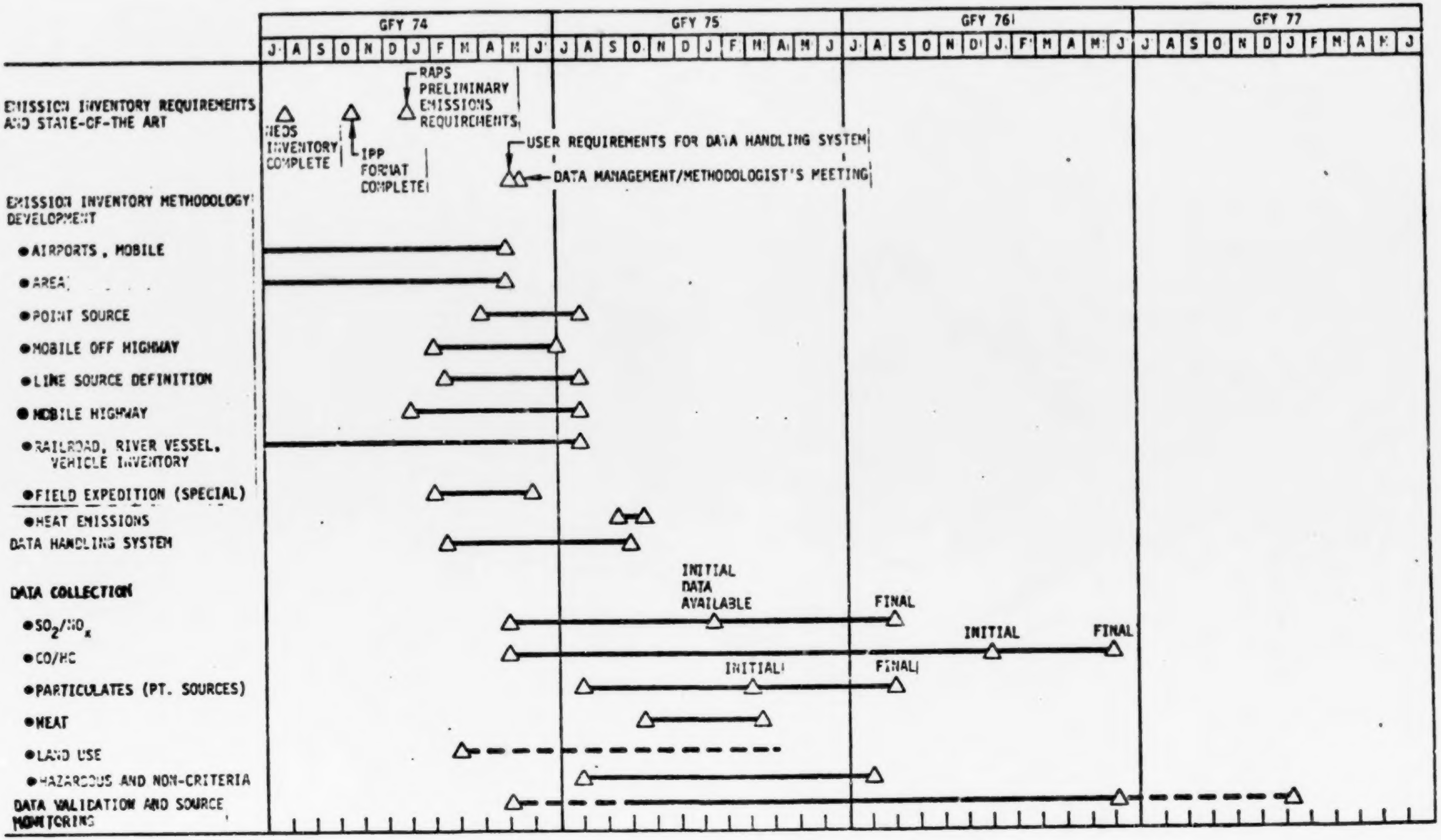


Figure 5. Schedule for Emission Inventory Activity

requirements and current state-of-the-art, 2) emission inventory methodologies (by source types), 3) emission inventory data handling system, 4) emission inventory data collection, and 5) data validation and source monitoring.

As indicated in Figure 5, the first step in this plan is virtually complete. The existence of the NEDS inventory for St. Louis in IPP format has been completed. This data base insures that emissions data are available for the early exercising of RAPS models. It is recognized, however, that such information (although capable of being used) is based upon an annual time scale and relatively low spatial resolution and is therefore inadequate to meet the final RAPS objectives. The recommended uses of the NEDS inventory (for RAPS purposes) are clearly indicated in the study by Stanford Research Institute, A Regional Air Pollution Study (RAPS) Preliminary Emission Inventory, under Contract 68-02-1026. This study presents an operational plan for providing emissions data for RAPS as well as reviews in detail the emissions models used in the past to provide emissions data.

The second major element in the emissions plan, establishment of methodologies for emissions data, is underway, either under contract or in cooperation with other governmental agencies. The objective of this effort is to develop a detailed methodology to acquire the data to bring the individual sources and emission inventory items up to the minimum specification of the RAPS. The data included in this methodology include emission estimates, operational variations (as a function of time of day, season, or year), product(s) produced, control equipment information, temperature, geographical identifiers and physical data such as stack height, diameter, etc.

Presented in Table 1 is a list of the participating groups with their respective responsibilities. Both the SRI report and the NEDS inventory provide the base from which these groups work. From this base, supplemental data requirements are identified which could include finer detail and analysis concerning process or operational variations or continuous emission monitoring

TABLE 1

PARTICIPANTS AND RESPONSIBILITIES FOR METHODOLOGY DEVELOPMENT (AND DATA COLLECTION) FOR RAPS EMISSION INVENTORY

Group	Classification	Nature of Effort*
AMC Rockwell International	Point Sources	M (+ D later)
GCA Corp.	Airports, mobile	M (+ D later)
ESE	Stationary Area	M (+ emission factors)
SWRI	Mobile, off-highway	M
DOT	Railroad, river vessels	M + D
WU	Mobile Source	Line Source, highway methodology for St. Louis
Dept. Federal Highway	Mobile, freeways	M + D
AMC Rockwell International	Special Expeditionary Support	M for emissions related to field expeditions
AMC Rockwell International	Heat Emissions	M + D

---

*M = methodology development

D = data collection

of selected (and identified) sources. Sensitivity analysis is then employed to determine the significance of these (potential) requirements. The completion date for all methodology development is March 1, 1975.

The third element of the RAPS emission inventory data handling system can be carried out in parallel with the methodology development element, but not completely independent of it. It is the objective of this effort to design, implement, execute, and demonstrate a system capable of recording, storing, retrieving, editing, and updating all data required for the computation of emissions on an hourly basis with a spatial resolution commensurate with RAPS modeling requirements.

We recommend that, for those models already identified in the detailed project breakdown structure (Appendix A), user (modeler) requirements of emissions data be specified by mid-March. It must be realized at the outset of this effort that the utility and efficaciousness of any data handling system will be determined to a significant extent by the incorporation of user design requirements. It is recognized that this requirement is difficult to achieve at this time (i.e., prior to exercising all of the RAPS candidate models); however, every effort must be made to specify the user design requirements.

We also recommend that meetings be established between key individuals in groups indicated in Table 1, EPA/RAPS emissions personnel, and the data handling personnel to insure the establishment of a properly designed data handling system.

The components required to complete the data handling system, which is being carried out via a task order agreement with the Rockwell Air Monitoring Center are:

- input record format and content design
- retrieval format design
- file design

- systems design
- systems implementation and software development
- demonstration

It is planned that this effort be completed by November 30, 1974.

The fourth major element given in Figure 5 (emission inventory activity) is data collection. This effort is designed to follow an iterative data upgrading procedure. With the currently available NEDS inventory, AQSM's can now be exercised. As methodologies are developed and data collection begins, the data handling system will be implemented; its designed capability of updating by source and/or by pollutant classifications insures the upgrade of the emission inventories as an on going activity.

We recommend that a mechanism be established to assure close working relationships at the NADB and Model Development Branch interface. This is essential for the RAPS objectives to be served.

The final element of the emission inventory effort is data validation and source monitoring, currently planned to be initiated in early GFY '75 for point, mobile and area source classifications. Although the nature and scope of the source testing and monitoring plans have yet to be specified, we concur with the SRI recommendations that, as a minimum, emphasis be given to emission validation during periods of intensive field activity.

Summary of Recommendations

The following recommendations are made:

- User requirements of the emissions data be specified by mid-October, 1974.
- Meetings be arranged between key individuals in groups indicated in Table 1, EPA/RAPS emissions personnel and the data handling personnel by mid-August, 1974, with the purpose of insuring that

the emissions data handling system design is compatible with the data being collected.

- A close coordination between EPA/RAPS Program Management, NADB personnel and Model Development be maintained.
- Data validation procedures be included as part of future methodology development upgrading.
- As soon as possible, a methodology for obtaining a land-use inventory be initiated and completed by December, 1974. As such an inventory is one of the basic differences between St. Louis and a different region, the RAPS models must be parameterized according to this information. The nature of this effort should be coordinated with J. McElroy of Monitoring Systems Research and Development Laboratory, NERC, Las Vegas

AEROMETRIC MEASUREMENTS

The aerometric measurements program constitutes the largest and most concentrated effort ever undertaken to define and describe the state of an urban atmosphere. As indicated in Figure 2, this program consists of: 1) an extensive (regional) ground-based air monitoring system (RAMS); 2) a vertical extension of the RAMS which consists of three fully-instrumented helicopters, one of which serves as backup; 3) an upper air sounding network, and 4) a series of concentrated field expeditions using portable samplers conducted during special periods.

Objectives of Aerometric Measurement Program

The objectives of the aerometric measurement program are:

1. Produce a documented and validated data base of sufficient scope (variety of meteorological/pollutant conditions in space and time) to support the objectives of the model development and evaluation program.
2. Extend the understanding of atmospheric phenomena as required to support the model development and evaluation program.

A Plan for Aerometric Measurements

In designing an operational plan for an aerometric measurement program, two guiding principles must be employed. First, the capricious nature of the weather requires a certain vagueness when it comes to specifying the scope of a data base required to meet the RAPS objectives. This will be particularly true in the early phases of the study and may be expected to improve in the latter phases. Therefore, extensive and continuous data collections are required despite the fact that the use of some data may be infrequent. Secondly, there must be specified predetermined periods wherein a maximal effort by all investigators toward the collection of data is made, i.e., a portion of time where most of the measurements are being made for most of the time. These periods are selected on the basis of historical meteorological/pollutant conditions.

The Regional Air Monitoring System (RAMS)

By any means of evaluation, the RAMS is a most essential element of the aerometric measurement program. It is the objective of this network to provide a long term, uniform, verified data base of ground-based measurements. In fulfilling its objective, the RAMS is expected to be used to test the ability of aerometric models to provide quantitative measures of regional air quality based exclusively on a monitoring network. It is presently projected to operate continuously over the two-year period from September 1974 to December 1976.

The RAMS consists of 25 remotely operated, automated stations controlled and polled via telemetry to a central data aquisition system. The stations are "managed" by a mini-computer which provide for automatic calibration of the pollutant gas instruments.

The principal features of the RAMS instrumentation are listed in Table 2. The allocation of special instrumentation is presented in Table 3. The site locations for the RAMS stations are shown in Figure 6.

The network layout, as well as cirteria for specific station sitings are presented in a paper by F. Pooler, "Network Requirements for the St. Louis Regional Air Pollution Study." A restatement of these criteria is outside the scope of this report. The stations are arranged in concentric circles centered on Site 101, located in downtown area just north and west of the St. Louis arch. The radii of the concentric circles are 4, 9, 20 and 40 km.

The RAMS will be operated for the EPA by the Rockwell Air Monitoring Center team through at least the first six months of its operation.

The Aerial Monitoring System

It is the objective of the aerial monitoring system, which is operated by NERC, Las Vegas, to provide a uniform data base for aerometric measurements aloft. The aerial system consists of three Sikorsky-58 helicoptors which have been modified to carry two complete aerial monitoring systems; the third unit serves as a helicoptor back-up only.

The principal features of the aerial monitoring system are given in Table 4. Industry-compatible tapes from the data acquisition system are to be translated and verified using the PDP 11/40 mini-computer at the RAPS St. Louis facility.

Data will be collected to yield vertical distributions and pollutant maps aloft. In addition to providing data for model validation, initial and boundary conditions will be obtained. Although the flight plans have not been formally finalized at this time, they will include the

TABLE 2

RAMS INSTRUMENTATION

Network

- 25 Stations
- Automatic operation, PDP - 11/40 central computer
- Telemetered digital information plus data acquisition each station
- 1-minute interrogation
- Display by CRT and printer/plotter
- Mag tape storage

Station Instrumentation (all stations unless specified)

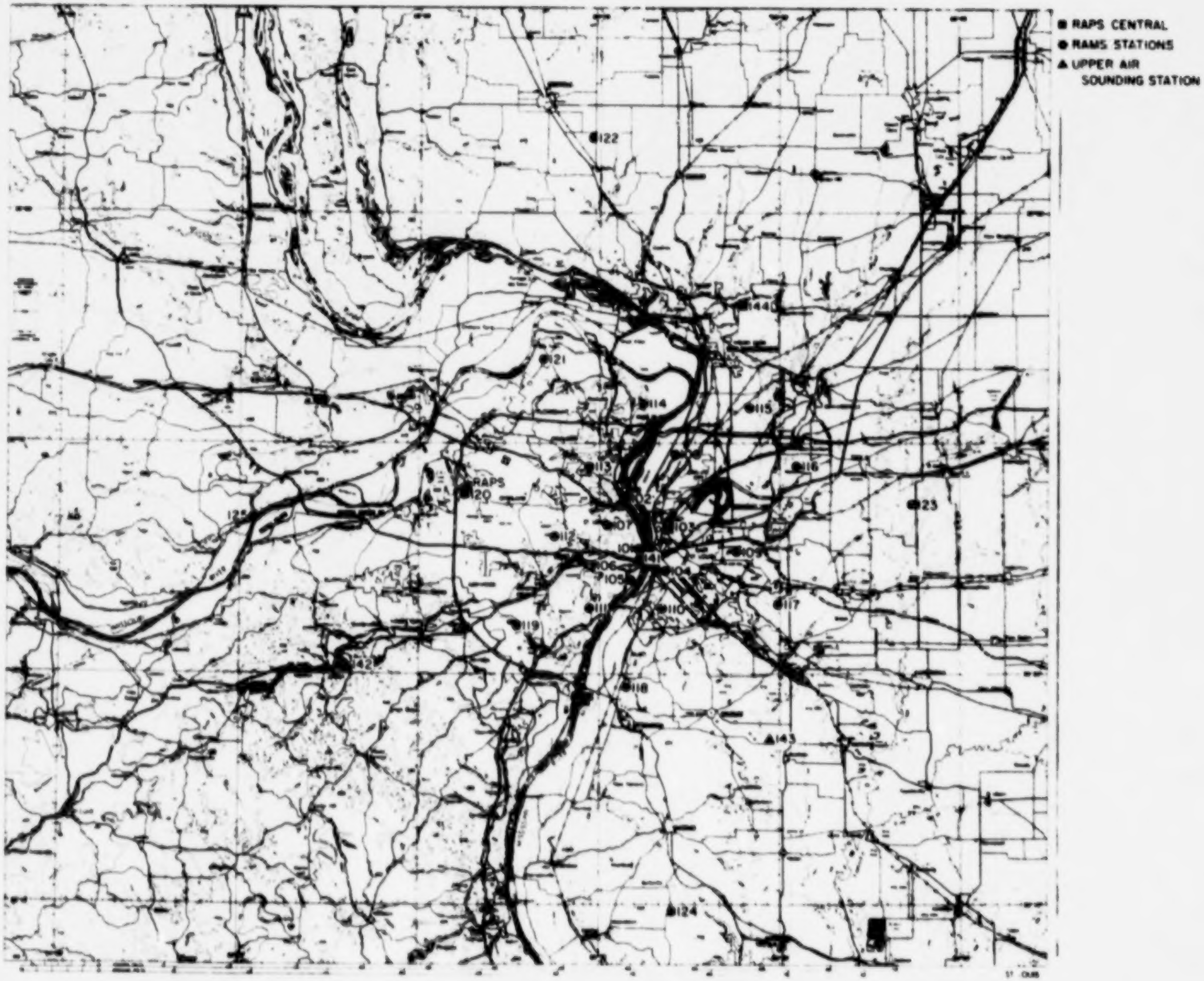
- Ozone
- NO, NO_2, NO_x
- CO, CH_4, NMHC
- Total Sulfur (12 sta)
- H_2S, SO_2, TS (13 sta)
- Gas Bag Samplers
- Particulates:
  - Hi-vol filters (10 sta)
  - Nephelometer
  - Dichotomous sampler (10 sta)
- Wind, speed and direction
- Ambient temperature
- Differential temperature (12 sta, 30-meters)
- Dew Point
- Pressure (7 sta)
- Solar radiation:
  - 4 stations:
    - three spectral pyranometers
    - one direct pyrehellometer
    - one long wave pyrogeometer
  - 2 stations:
    - two spectral pyranometers
- Turbulence (5 sta, u, v, w, local recording only)

TABLE 3

SPECIAL DISTRIBUTION OF INSTRUMENTATION FOR ST. LOUIS RAMS

Station ID	Complete Radiation	Simple Radiation	Turbulence	Temp Diff	Pressure	Sulfur G.C.*	Hi-Vol	30-m Tower	Dichotomus Sampler
101				x	x	x		x	
102				x				x	
103	x					x	x	x	x
104		x		x		x		x	
105			x	x		x	x	x	x
106				x		x	x	x	x
107			x	x				x	
108		x				x	x		x
109			x	x	x			x	
110									
111			x	x				x	
112				x	x		x	x	x
113			x	x		x		x	
114	x					x			
115						x	x		x
116						x			
117									
118	x						x		x
119								x	
120						x	x	x	x
121						x			
122	x			x	x	x	x	x	x
123				x	x			x	
124					x		x	x	x
125					x			x	

*Remaining 12 stations receive Total Sulfur only


■ RAPS CENTRAL
● RAMS STATIONS
▲ UPPER AIR SOUNDING STATION
122
121
114
115
116
113
RAPS
120
123
125
112
107
102
103
101
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142
118
143
124
144

Figure 6. Geographical Locations of RAMS Stations

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TABLE 4

HELICOPTER INSTRUMENTATION

Type Instrument	Model Designation	Quantity
Fluorescent particle counter	MEE 110	2
Particle size counter	Royco 220	2
Nephelometer	MRI 1550B	2
NO-NO_x analyzer	TECO 14B	5
O_3 analyzer	REM 612B	3
CO analyzer	Andros 7000	2
SO_2 analyzer	Meloy SA 160	2
CH_4 - THC analyzer	MSA 11-2	2
Bag Sampler	EPA	2
Temperature and dewpoint	Cambridge CS-137	2
Pressure altimeter	Computer Instrument Corp.	2
Data logger, A/D converter	Monitor 7200	2
Tape deck	Cipher 70SE	2
Strip Chart, 4 channel	MFE M-24 CRAHA	2

capability of providing time histories of boundary conditions.

The general aspects of the flight plans call for two missions per day with the two helicopters flying in concentric circles -- the inner flight circle covers the core of the RAMS while the outer flight circle covers the outer RAMS sites. Each flight is intended to be approximately two hours in duration with the first starting at 0600 and the second at approximately 1330. To the circular horizontal flight pattern will be added seven to eight downward spirals (for each helicopter) with the location of spirals chosen as closely as possible to the RAMS site. Vertical profiles will be obtained from near ground level to 200-500 ft. (61 - 152 m) above the top of the inversion.

Although discussed informally from time to time, more serious consideration should be given to nighttime flights. These are particularly valuable in establishing initial and boundary conditions as well as determining the formation and disappearance of materials in the absence of solar radiation.

The helicopter aerial monitoring operations are scheduled during field expeditionary periods from August 5, 1974 through 1976. A total flight time of approximately 20 hours per week per helicopter is planned during each expeditionary period.

For the immediate helicopter program, we recommend that debriefing reports and procedures be established following each mission. These will not only aid in data interpretation efforts later, but would be of significant value in the data validation procedure. We also recommend that photographs of observations be included as part of each mission and that these be logged into the RAPS data base.

Finally, we recommend that consideration be given soon to the incorporation of particle collection devices compatible with (subsequent) chemical analysis. Although we have sulfate and nitrate analyses in mind, heavy metals analyses, via X-ray fluorescence, would be of definite value in assessing the variety of probable mechanisms for sulfate and possibly nitrate formation. The SO_2 oxidation rate (which leads to sulfate formation) in aerosols is known to be enhanced by the presence of heavy metals (e.g., Mn^{++}).

Upper-Air Sounding Network(UASN)

The RAMS network provides a relatively dense data base of surface winds, temperature and relative humidity. The combination of these data with those obtained from upper-air soundings allows the determination of changes in winds, local stability, and mixing depth throughout the area, particularly as they relate to terrain features and synoptic scale meteorology. It is the objective of the upper-air sounding network to provide a data base of the upper air structure over the St. Louis AQCR. This data base will consist of winds, temperature, dew point and relative humidity aloft. Special emphasis is given to the lower ($\leq$ 700 MB) levels. Temperature resolution is ± 0.5° C. The frequency of observation of winds aloft is every 30 sec.

This sounding network consists of four fixed stations which have been given numerical designations of 141 through 144. Their locations are indicated on Figure 6. Table 5 shows the periods of operation and kinds of soundings taken for each site.

The simultaneous operation of the upper-air sounding network and RAMS will provide: 1) a means of correlating air quality measurements with mean transport across the St. Louis ACQR: 2) determination of variations in mixing heights; and 3) definition of atmospheric stability classes associated with the distribution of pollutant concentrations in the St. Louis AQCR.

Installation and operation of the network, which includes quality control procedures, is the responsibility of the Rockwell Air Monitoring Center. Data from the upper air sounding network will be available on a semi-real time basis for forecasting purposes during intensive periods of study as

TABLE 5

SUMMARY OF UPPER AIR SOUNDING NETWORK

Station ID	Period(s) of Operation	Soundings	
		Rawinsondes	Pibals
141, 142	5 days/week, 24 hrs/day from October 1974 thru December 1976; 7 days/week during the intensive study periods	4 per day at 6-hour intervals to 9.8 kft (3.0 km)	20 per day at hourly intervals between radiosondes
143, 144	7 days/week, 24 hrs/dy during the intensive study periods	Same as 141 and 142	Same as 141 and 142

well as in a form suitable for subsequent entry into the RAPS data bank. Graphical data will be provided on standard NOAA low-level sounding adiabatic charts. Radiosonde angular observations and reduced radiosonde wind directions, wind speeds, and heights are provided on formatted forms designed for 30-second intervals and consistent with the requirements of the RAPS Data Manager. Pibal theodolite data are provided also on formatted forms designed for 30-second intervals. It is recommended that post-analysis summaries of meteorological conditions be available to the RAPS participants during the intensive expeditionary periods.

Field Expeditions

A great body of earlier work has demonstrated that the observational data base required for model validation substantially exceeds that provided by a routine monitoring network. Thus, the principal objective of the field expeditions is to supply short term, detailed atmospheric observations in support of the development and validation of the RAPS aerometric models. Based on present knowledge, there are four major classes of expeditions (as shown in Figure 7). The objective of each is described as follows:

1. Meteorological Characterization

Objective: To supplement the routine meteorological elements of the RAPS with data sufficient to characterize the micro-scale and boundary layer phenomena with respect to its varying (spatial and temporal) mechanical, thermal and optical properties. Successful completion of this element of the RAPS can only be achieved if a land use inventory is available. It is recommended that arrangements for this be started immediately.

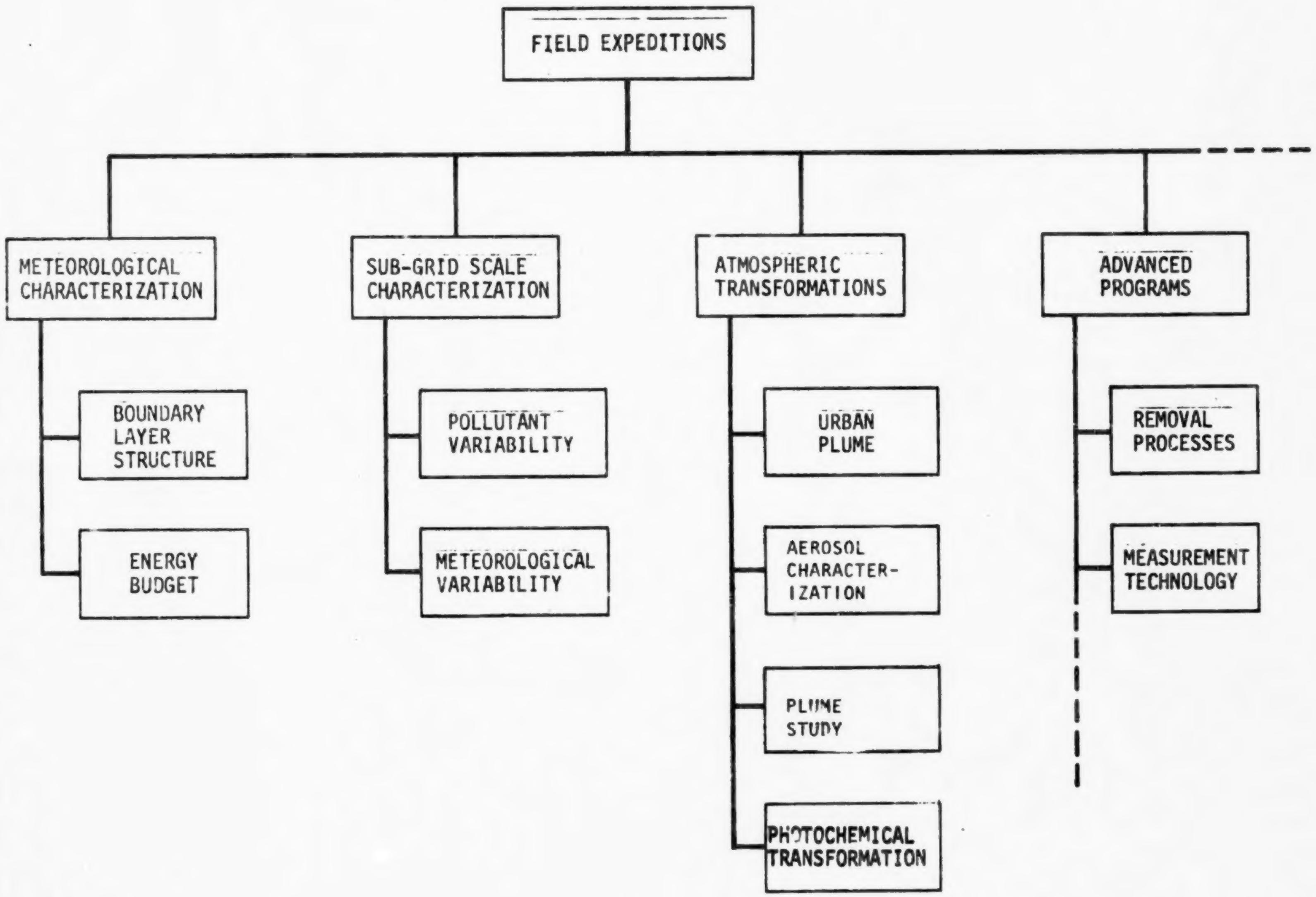
FIELD EXPEDITIONS
METEOROLOGICAL CHARACTERIZATION
BOUNDARY LAYER STRUCTURE
ENERGY BUDGET
SUB-GRID SCALE CHARACTERIZATION
POLLUTANT VARIABILITY
METEOROLOGICAL VARIABILITY
ATMOSPHERIC TRANSFORMATIONS
URBAN PLUME
AEROSOL CHARACTERIZATION
PLUME STUDY
PHOTOCHEMICAL TRANSFORMATION
ADVANCED PROGRAMS
REMOVAL PROCESSES
MEASUREMENT TECHNOLOGY

Figure 7. Elements of Field Expeditionary Programs

2. Sub-Grid Scale Characterization

Objective: To develop and implement a methodology to establish a relationship between stationary point (RAMS) measurements and average measurements in a grid approximately one km square.

3. Atmospheric Transformations

Objective: To characterize the complex physical and chemical transformations of an air mass over the St. Louis region.

4. Advanced Field Programs *

Objective: To enhance the RAPS data base by a) improving the phenomenological characterization of uncertain processes, such as removal processes and interactions with water clouds and precipitation, and b) developing new measurement techniques for characterizing trace constituents in urban areas, especially related to the sulfur cycle.

Each of the four classes of expeditionary projects listed above can be further subdivided. At the outset we make two recommendations. First, we recommend that uniformity be adopted with respect to the periods within each season that field expeditions are to be conducted. The need for this already has been mentioned (Page 19). Second, we recommend that field expeditions conform to a schedule which consists of the following phases: 1) an experimental design phase at the end of which its approval from EPA/RAPS management is obtained; 2) a preparation phase; 3) a measurement or an experiment phase; and 4) a data validation and analysis phase. Discussions with the majority of the RAPS investigators lead us to believe that these recommendations are acceptable.

Meteorological Characterization. Referring once again to the elements of the Field Expeditionary Program (Figure 7), it is seen that the meteorological characterization experiments consist of atmospheric boundary layer

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* The function of this class of expedition is to provide flexibility to RAPS experiments in allowing for growth into new areas which appear promising (but whose technology may not be well established)

structure and energy budget studies. This work is planned to be performed primarily by EPA/ML staff, supported by Rockwell Air Monitoring Center.

Boundary Layer Structure

Objective/Purpose: Experimentally specify the three-dimensional structure and temporal variations of the boundary layer over the St. Louis region in order to define model boundary conditions, to parameterize the turbulent mixing processes, and to validate and advance the model development and evaluation program.

Approach: This study is to be divided into two phases. The first consists of defining and specifying the boundary layer structure, while the second phase will consist of validation and verification via tracer studies. Daytime and nighttime measurements will be made. Vertical temperature profiles from aircraft (helicopter and fixed wing) ascents will be made with major emphasis being given to the region at the top of the mixing layer. Due to the lowering of the mixing layer at night, the time for each profile is reduced which allows an increase in the number of ascents. Other measurements to yield vertical wind profiles and horizontal trajectories will be made to supplement the upper-air sounding network. In addition, lidar scans of the aerosol loading to determine the degree and variations in mixing will be made.

Schedule: Effort on Phase I began in 1973 and is currently planned through summer of 1975. The experimental activity on Phase II is scheduled to begin in summer of 1975 and extend through 1976.

Energy Budget

Objective/Purpose: Experimentally determine the components of the energy budget over the St. Louis AQCR, document differences in urban and rural energy budgets for the surface (land use) and boundary layers, and quantitatively assess the effects that variations in the energy budget have on the boundary layer.

Approach: The study is divided essentially into three parts: the determination of (1) the radiation, (2) the sensible heat flux, and (3) the energy storage terms of the energy balance equation. To determine the components of the radiation term, airborne and ground-based measurements will be made over rural and urban areas. The airborne program will provide measurements of the surface albedo over representative land use areas and vertical solar flux measurements. Airborne measurements include six pyranometers, three of which look up and three look down in order to measure the incident global solar irradiance in UV, visible and IR bands. Ground surface temperature, dew point and aerosol measurements will be made.

The sensible heat flux term will be determined via airborne and ground-based measurements using the eddy correlation method. Two approaches will be used: the first (airborne)employs taking the product of the coincident measurements of turbulent vertical velocity and temperature fluctuations, while the second (ground based) uses a device called a fluxatron, which makes the above computation in "real-time."

The storage term will be measured by imbedding thermistors at various depths below representative surfaces at RAMS sites.

Schedule: Initial efforts begin in the Summer, 1974 with the exeption that measurements of the storage term are not planned. These (latter) measurements will begin in the Fall, 1974 period. The energy budget study is planned to continue through 1976.

Sub-Grid Scale Characterization. The criteria employed for siting RAMS stations were instituted to provide data representative of the area monitored, i.e., to minimize unrepresentative siting effects. Similarly, instrument related errors are minimized through the quality control (QC), quality assurance (QA), and data validation (DV) procedures used in the RAMS measurements. Sub-Grid Scale Characterization Studies are planned in order to assess quantitatively the nature of these fluctuations and, in turn, the representativeness of the RAMS air quality and meteorological observations. The studies will also allow assessment of the degree of ambient variability (involved in the verification of computations) depends upon emissions field and land use variations. They will be conducted initially on an exploratory basis as functions of selected meteorological conditions and various source-receptor combinations deemed most important by the model development and evaluation team. Moreover, the scope of these studies must be sufficiently large to permit a determination of the extent to which the observed variabilities are determined by both emissions and land use variations. It is clearly recognized that without such a determination the transfer of RAPS models to other ACQRs would be speculative, however without any experimental data, specific field studies related to the assessment of emission and land use variations cannot be recommended. It is recommended that these studies be followed very closely as they are of great significance to the model verification and evaluation portion of the RAPS. Furthermore, it is through these studies that one of the most vital interfaces of RAPS participants--that of the interface between the participants involved in modeling, meteorological measurement, emission measurement and the investigation of atmospheric chemistry and physics processes--will be established.

The studies currently planned are: 1) Pollutant Variability, and 2) Meteorological Variability. It can be expected that the scope of these studies will expand and, although specific studies are not recommended, field programs which examine sub-grid emission variabilities and land use variabilities should be anticipated. These latter studies may be more theoretical than experimental initially and some field work should be expected.

Pollutant Variability

Objective/Purpose: To determine, for specified grid areas, the pollutant heterogeneities (or homogeneity) in order to parameterize the relationship between point (station) measurements and grid-averaged measurements.

Approach: The basis for the approach is the use of mobile units carrying an array of air quality instrumentation and individual, portable sampling units. Bag samplers are also included. In addition, long-path optical measurement techniques will be employed, including laser and non-laser techniques. The initial efforts on the PV Study will be to develop a coordinated methodology; more extensive field expeditions will occur during subsequent periods. In the initial efforts, measurements of SO_2, O_3 and CO will be made with the portable sampling units, while with the mobile unit, NO_x, hydrocarbons and aerosol (nephelometry) measurements will also be possible. This collection of instrumentation will be used in two ways. Firstly, at specified RAMS sites (initially 103, 105, 108 and 123) the portable sampling units will be used to validate the time and spatial averages determined from the long-path methods. Secondly, the portable and mobile units will be deployed to determine the spatial and temporal pollutant variability. For both measurements, the methodologies would be the same, i.e., the sampling unit will either travel along prescribed paths or be stationed along prescribed paths. In either case spatial and temporal variabilities are obtained from which averages and their variances can be calculated which would then provide information with which the RAPS AQSMs would be compared. Finally, in these initial phases, the mobile (Winnebago) monitoring unit will serve as the principal means by which preliminary surveys of pollutant variability for candidate grid areas are made. The unit is equipped with instrumentation which will allow its position to be located during movement.

Schedule: Initial measurements in St. Louis at sites 103, 105, 108 and 123 will begin in mid-July, 1974 for SO_2, O_3 and CO, with some hydrocarbon, NO and NO_x measurements done in an exploratory manner. With the field methodology developed and refined and the RAMS fully operational, the program should be expanded in the winter, 1975 period.

Meteorological Variability

Objective/Purpose: To determine, for specified grid areas, the meteorological heterogeneity in order to parameterize the relationship between point (station) measurements and grid-averaged measurements.

Approach: The basis for the approach is to employ a mobile van traversing specified 1 km^2 grid areas possessing relatively homogeneously (i.e., approximately the same aerodynamic roughness) land use patterns.* The van will make temperature and moisture measurements initially. Current plans call for the van to first take measurements along the grid perimeter and then enter the grid and take measurements by traveling a saw-tooth route. The measurement period is completed by retracing the route about the grid perimeter. This cycle is repeated on an hourly basis during transitional periods. It should be expected that this effort will increase in scope in subsequent expeditionary periods.

Schedule: Exploratory studies of the type outlined above will begin in summer, 1974 program over only one land use area. Candidate areas are: downtown, old residential, new residential and heterogenous areas (50% park and 50% houses).

Atmospheric Transformations. It is the objective of the five studies indicated here to characterize, in either physical or chemical terms, the transformations taking place in a moving air mass as it moves across the city and into the surrounding area. Existing AQSMs currently account for SO_2 transformations, simply via an empirically derived disappearance rate factor. Laboratory studies establish that the observed factors are much too fast to be due solely to photooxidation via direct photoexcitation of SO_2. A myriad of other processes are possible, which include other photooxidation routes, and range from homogeneous chemical to heterogeneous chemical and physical processes. The relative importance of any one process has yet to be established. The success of the RAPS will be determined partially by success in this area. The time frame and available monetary resources of the RAPS requires emphasis

*The need for a land use inventory for St. Louis is once again indicated here.

on field studies; nevertheless, semi-controlled experiments (e.g., bag irradiation of St. Louis air samples) are required.

The studies planned are: 1) Urban Plume, 2) Aerosol Characterization, 3) Point Source Plume and 4) Bag Irradiations.

Urban Plume Study

Objective/Purpose: To determine urban plume size and composition under a variety of meteorological conditions in order to identify the major rate processes, such as chemical reactions, gas-particle conversion and dry deposition (removal), which take place in the urban air mixture.

Approach: The basis of the approach is the use of an instrumented aircraft. Flight patterns and measurements are made which lead to the construction of three dimensional maps of gaseous pollutant concentrations, particulates, and related meteorological parameters. Measurements of SO_2, O_3, CO, NO, NO_2, total light scattering, CNC, sulfate and particle size are made. Cross-sections of the urban plume are determined by making three to five traverses across the plume at different altitudes at the top and within the mixing layer and for three to five distances downwind of the urban complex.

Using wind field data, the total flux of pollutants are determined and compared with the corresponding emission flux to assess the importance of conversion processes and/or the quality of emission inventories. By comparing SO_2 to total sulfur ($SO_2 + SO_4^=$)at various distances downwind, the importance of chemical conversion can be determined; by comparing the changes in the total mass of the aerosol and size distributions, gas-particle conversion rates can be estimated. These determinations, when combined with emissions data and vertical pollutant profiles, afford a method for determining the importance of dry deposition. (Note approach to study of removal processes, where the determination of the deposition velocity of SO_2 on three to five representative surface classifications is described.)

Schedule: Exploratory measurements were completed in summer, 1973 which demonstrated the feasibility of the above approach as well as providing useful data. Additional experiments are planned to begin in August, 1974 and the winter of 1975.

Aerosol Characterization

Objective/Purpose: To characterize the aerosols sampled in the St. Louis AQCR in terms of their physical and chemical properties and their probable origins and evolution.

Approach: An extensive array of instruments and devices are assembled into two moveable laboratories, each with a computer compatible data acquisition system, in order to measure the chemical and physical properties of the St. Louis aerosol. One of the units makes both chemical (vapor and particulate) and physical measurements, while the second investigates principally the optical properties. Measurements are made in either real time or (in the case of aerosol samples) collected for subsequent chemical analysis using XRF, NAA, HRMS, ESCA and more traditional methods. In addition, a network of portable aerosol (Nelson) samples located at the RAMS sites will be operated.

Schedule: This program started in the summer, 1973 period and measurements were made in the winter of 1974. Measurements will also be made in summer, 1974 period as well as the winter, 1975 period. During the 1974 program this study is to be closely coordinated with the urban plume and point source plume studies. This will require that the relatively immobile trailers be placed in representative locations.

Plume Study

Objective/Purpose:

1) To determine the diurnal variation in sulfur dioxide and the extent to which it is converted to sulfate in plumes (in order to elucidate the role played by humidity).

2) To determine the rate of oxidation of nitric oxide to nitrogen dioxide and the extent to which nitric acid is formed in power plant plumes.

Approach: The basis of the approach is to use a fixed wing aircraft containing real-time gaseous monitors and particle sampling devices to provide the construction of three-dimensional maps of a power plant plume at numerous downwind distances. Both plume location and pollutant dilution are determined by using SF_6 tracer techniques (frontal chromatography with EC detection). In addition, measurements of SO_2, $SO_4^=$ (Isotopic Ratio Tracer method), NO, NO_2 and HNO_3 are made. SF_6/SO_2 ratios for the various downwind distances yield SO_2 loss rates (other than by dilution) while $SO_4^=$ measurements yield $SO_4^=$ formation rates. Similar analyses allow determination of NO_2 and HNO_3 formation rates.

Schedule: Exploratory measurements were made in mid-June, 1974 and more extensive measurements are planned for the summer, 1974 period. Additional measurements are planned for the winter, 1975 period. It is recommended that the aircraft be outfitted with an ozone chemiluminescent monitor. Moreover, it is recommended that particulate samples be collected for subsequent heavy metal analysis and ESCA. Finally, the measurement capabilities should be expanded to include particle size distribution mapping.

Photochemical Transformation (Bag Irradiation) Study

Objective/Purpose: To ascertain the photochemically stimulated transformations in the sulfur cycle in order to develop a chemical kinetic model of the processes involved.

Approach: The initial approach taken in this study will be to isolate chemical effects from meteorological and variable emissions effects by irradiating representative atmospheric samples in irradiation chambers In these studies Tedlar bags are used and irradiations are conducted at the Central RAPS St. Louis facility. Two identical air samples are collected in the bags. The contents of one bag is modified either by the addition or removal of particular materials. During the simultaneous irradiation of the two bags the comparative results are noted and related to known and/or postulated chemical and physical phenomena. The processed data are sent to SAI for chemical kinetics model development work. Initial experiments will determine: 1) the effects of SO_2 on NO oxidation and O_3 formation, 2) the effect of toluene on smog formation, 3) the effect of particulates from auto exhuast, and 4) effect due to atmospheric dilution with clean air. Measurements of SO_2, NO, NO_2, O_3, CO, non-CH_4, CH_4, hydrocarbon distribution, CH_3, CHO, PAN, particle size and % RH are made. Measurements of other sulfur compounds should also be included. If not in these initial experiments, measurements of H_2S and other reduced sulfur compounds should be planned for later efforts as they are known to react with O_3 in the presence of particles. Irradiation intensity is determined by measuring the disappearance of NO_2 during an experiment containing NO_2 and N_2 only.

Schedule: Initial experiments are scheduled to begin during the summer, 1974 expeditionary period, using the above approach. It is recommended that for subsequent experiments ammonia measurements, as well as sulfate measurements, be made if the results of these initial experiments warrant it.

Advanced Programs (Recommended). The studies in this classification represent activities that are important to RAPS objectives but represent a leading edge of knowledge that may be of principal significance in pollutant material balance or in characterizing materials that heretofore have not been measurable (reliable or otherwise). It is expected that, with further definition, portions of these studies would become independent studies or be incorporated into an expanding study already mentioned.

Removal Processes

Objective/Purpose: To determine the rate of removal of SO_2, CO and NO_x via dry deposition (surface absorption and adsorption on ground and vegetation), aerosols and water cloud processes.

Approach: In initial study efforts the basis for determining the dry deposition of SO_2 (as a function of different land classes) involves the use of the flux gradient method where the deposition velocity is defined through the mass transfer relationship and experimentally determined via direct measurement of SO_2 vertical concentrations gradient near the surface. Measurements made over areas of homogeneous surface types (3 to 5 different surface classifications), using an instrumented mobile van and 10 m tower (with automatic recording capability), is the basic measurement system.

Plans for an expanding effort must be forthcoming and this effort must include (in addition to increasing the scope of the SO_2 measurements) measurements for CO and NO_x. In laboratory studies, it has been shown that CO concentrations are very effectively reduced by ground absorption processes (specifically, bacterial activity). O_3 has not been given as great as an importance in these efforts because of the low concentration levels and the difficulty in measurement of gradients. The design of all of these experiments, as a minimum, requires knowledge of the St. Louis AQCR land use. Measurements over vegetative (three to five classifications), soil and covered surface (cement, blacktop, etc.) areas throughout the day for different stability classes are required in order to elucidate the diurnal variations due to plant and bacterial activity (for the different modeling classes). Use of the gradient method provides the basis for a measurement approach.

The interface of the Removal Process Study with the Aerosol Characterization Study is apparent. As the nature of the data from this study becomes available (size spectra as well as chemical composition), an experimental approach to refine the gas-particle removal process can be developed. Although this is one of the goals of the Aerosol Characterization Study, the removal process aspects should be brought out separately and given greater focus after the development of the St. Louis aerosol data base. It is intended that this will insure important direction and definition in future field studies.

In order to elucidate the importance of precipitation scavenging in the removal process (to include the transport of material to the scavenging site, in-cloud scavenging by the cloud elements and precipitation and below-clowd scavenging by the precipitation) it is recommended that use be made of the METROMEX/RAPS interface. Through the acquisition of only a few pollutant monitors and their use in the METROMEX aircraft, important data may be acquired. The principal disadvantage with this approach is the time differences between the RAPS and METROMEX schedules.

Schedule: Initial measurements of SO_2 deposition were scheduled to begin in the summer 1974. Measurements under the recommended program of expanded scope should start no later than the winter, 1975 expeditionary period. Initially, the expanded effort should coincide with those RAMS stations which possess the turbulence instrument package. Design of the study requires the availability of a land use inventory. Efforts to secure this must be forthcoming. Additional instrumentation is also required. At a minimum this will require approximately 10 - 15 additional pollutant monitors. The results of the initial SO_2 Dry Deposition Study should be studied closely. If the gradient method employed is deemed successful, then additional (three to five) instrumented mobile 10 m towers will be required. These are available from the NERC-LV. Data acquisition and processing systems may be obtained from those portions of the EPA CHESS program which have been replaced by the CHAMP network.

Measurement Technology (Recommended)

Objective/Purpose: To make the EPA/RAPS management aware of new, significant advances in measurement principles and technology as it relates to the model development and evaluation program and the aerometric program. In addition to the measurement of substances deemed important, but heretofore not measured or measureable, emphasis is placed on QC and QA practices.

Approach: At least three important activities are currently required. The first, a NO_2 monitor comparison test, consists of comparing the NO_2 chemiluminescent monitor with a NO_2 laser induced fluorescent monitor. This comparison will be made in St. Louis. The second activity is the application of a recently developed sulfuric acid monitor to the RAPS. Although not completely field evaluated at this time, the field performance of this instrument is expected to be characterized prior to completion of RAPS field studies. Progress toward achieving field reliability should be monitored closely. Such an instrument, when implemented on even a limited basis, would provide the extremely valuable data needed for elucidating the role this material plays in the SO_2 oxidation/sulfate formation mechanism. The third need, currently not planned but strongly recommended, is the establishment of a mobile quality control unit. As a minimum this unit would contain a complete set of air quality and meteorological instruments (including devices required for their calibration). This unit would serve as the focal point for all measurement related quality control activities (e.g. calibration of RAPS measurement systems and intercomparisons between RAPS measurement systems).

Schedule: The NO_2 monitor comparison is to begin during the Summer, 1974 expeditionary period. The initial comparisons will be between a Bendix NO-NO_2-NO_x monitor and the Aerospace Corporation NO_2 fluorescence monitor. It is recommended that this comparison be made during each of the expeditionary periods for at least one year. Furthermore, it is recommended that as soon as possible a comparison be made at one or more of the RAMS stations. This allows a more direct comparison with the RAMS' NO_2 monitor which is manufactured by Monitor Labs. The particular RAMS station should be selected following a review of the overall RAMS data in the late fall 1974.

At this writing, there exist no definite plans for application of the sulfuric acid monitor in the RAPS. It is recommended that arrangements begin in September to have the existing unit field operated in St. Louis during the winter 1975 period. If the results are encouraging, a broadened program should be developed for the summer 1975 expeditionary period.

Moreover, it is recommended that consideration be given as soon as possible to placing sulfuric acid monitors in the RAPS Aerial Monitoring System (the helicopters).

As with the development of a program for use of sulfuric acid monitors, no plans exist for use of a QC van. It is recommended that such a van be equipped for and operated during the winter 1975 period. Based upon the number of expeditionary measurement systems currently participating in the RAPS (mobile units, trailers, aircraft, etc.), as well as the extent of the St. Louis AQCR, this QC van can be expected to be utilized virtually full-time during the expeditionary periods.

Recommendations

The following recommendations are made:

- Uniformity should be adopted with respect to the periods within each season that field expeditions are to be conducted.
- Each study program should maintain conformity to a schedule consisting of the following four phases:
  1) experimental design with EPA/RAPS management approval;
  2) preparations; 3) measurements; and 4) data validation and analysis.
- With the coordination of the Meteorology Laboratory, Chemistry and Physics Laboratory, and the National Air Data Branch, action should be taken to start development of the St. Louis AQCR land use inventory no later than October 1, 1974.
- Special awareness should be given to the Sub-Grid Scale Characterization program.
- Greater emphasis should be given to Removal Process studies. Although some experiments are now planned, this area requires more attention.
- The development of field programs focussed on the sulfur cycle should be closely monitored.
- An advanced program concept should be added which consists of early activities that can be expected to play an important role in meeting the RAPS objectives (e.g., an NO_2 monitor comparison test and a program for use of sulfuric acid monitors are two specific recommendations).
- A mobile quality control van should be equipped and placed into service during the winter 1975. The unit should contain a complete set of air quality and meteorological instrumentation and serve as the focal point for all measurement related QC activities during the expeditionary periods.

DATA MANAGEMENT

Just as the Model Development and Evaluation Program provides the direction and focus for the RAPS, so the Data Management effort serves as the "glue" which keeps the RAPS together. The massive quantities of data from the RAMS, the great variety of data from the Field Expeditionary and Emission Inventory Programs and the large number of organizational entities, personnel and scientific disciplines presents the RAPS with an extraordinary data management task.

Objective of Data Management Effort

The objective of the data management effort is to develop and maintain a data management system responsive to user requirements within the framework of RAPS objectives. At the same time data integrity must be maximized and the impact on computer resources minimized. This requires efficient storage and retrieval software, simple on-line display and analysis capability, timely distribution of data in user specified formats, periodic data base summary reports and adaptability to changing needs and schedules.

A Plan for Data Management

In addition to the final operations phase, the data management task can be divided into design and implementation/demonstration phases. Figure 8 illustrates a logic flow diagram for planning this effort. For the most part Mr. R. Browning has implemented a plan for the development of a data management system which leads to the elements illustrated to the right of Figure 8.

Separate from the management of data from the routine measurement elements (RAMS and Upper-Air Sounding Network, etc.) and consistent with the user oriented data management objective, Mr. Browning has requested data plans from each RAPS principal investigator prior to each field expeditionary period. This data plan is used by the data management personnel to prepare software for acquisition, storage, retrieval and analysis. Additional description of this plan is deferred to sections in this report describing the experimental design and preparation of phases of the field expeditionary program.

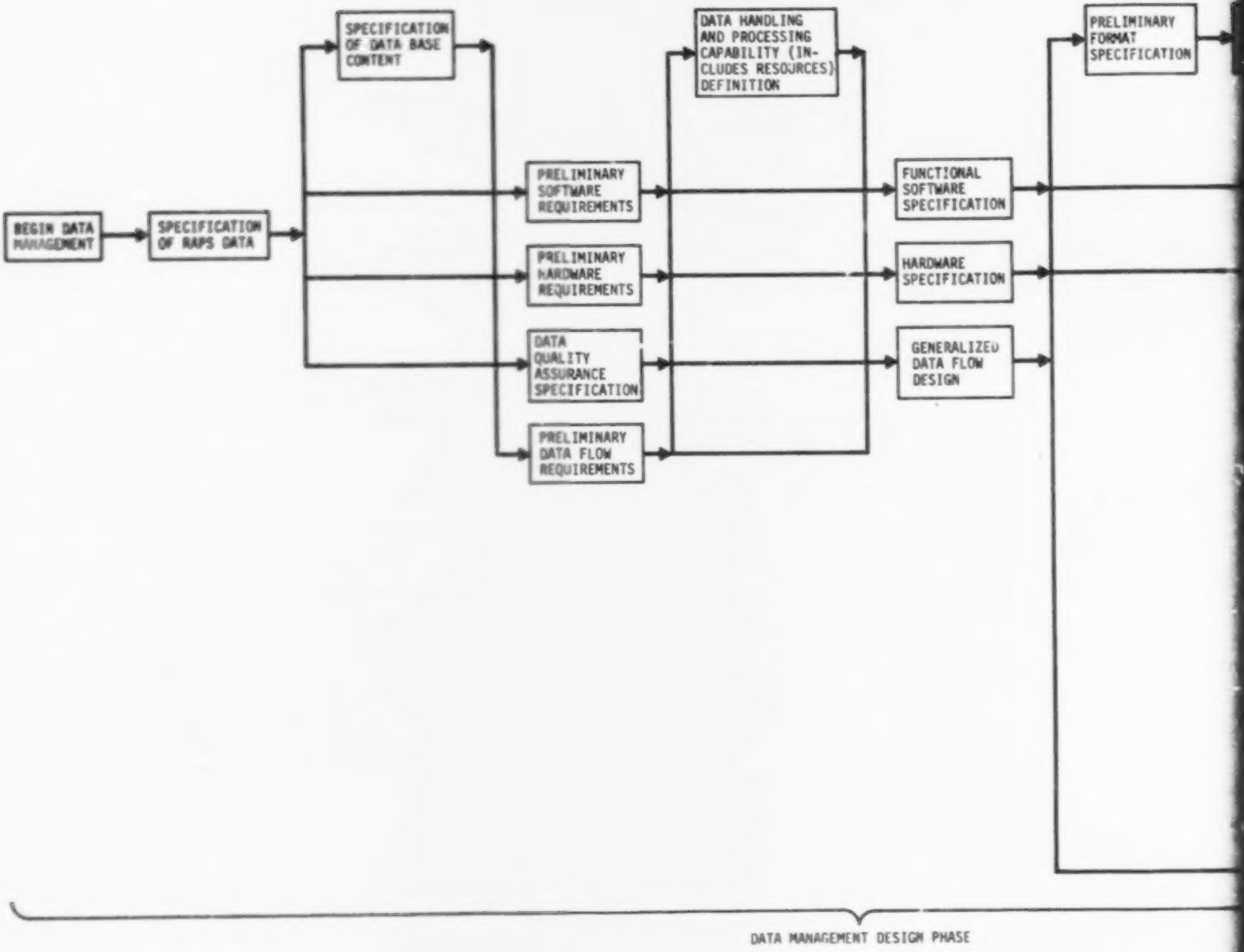
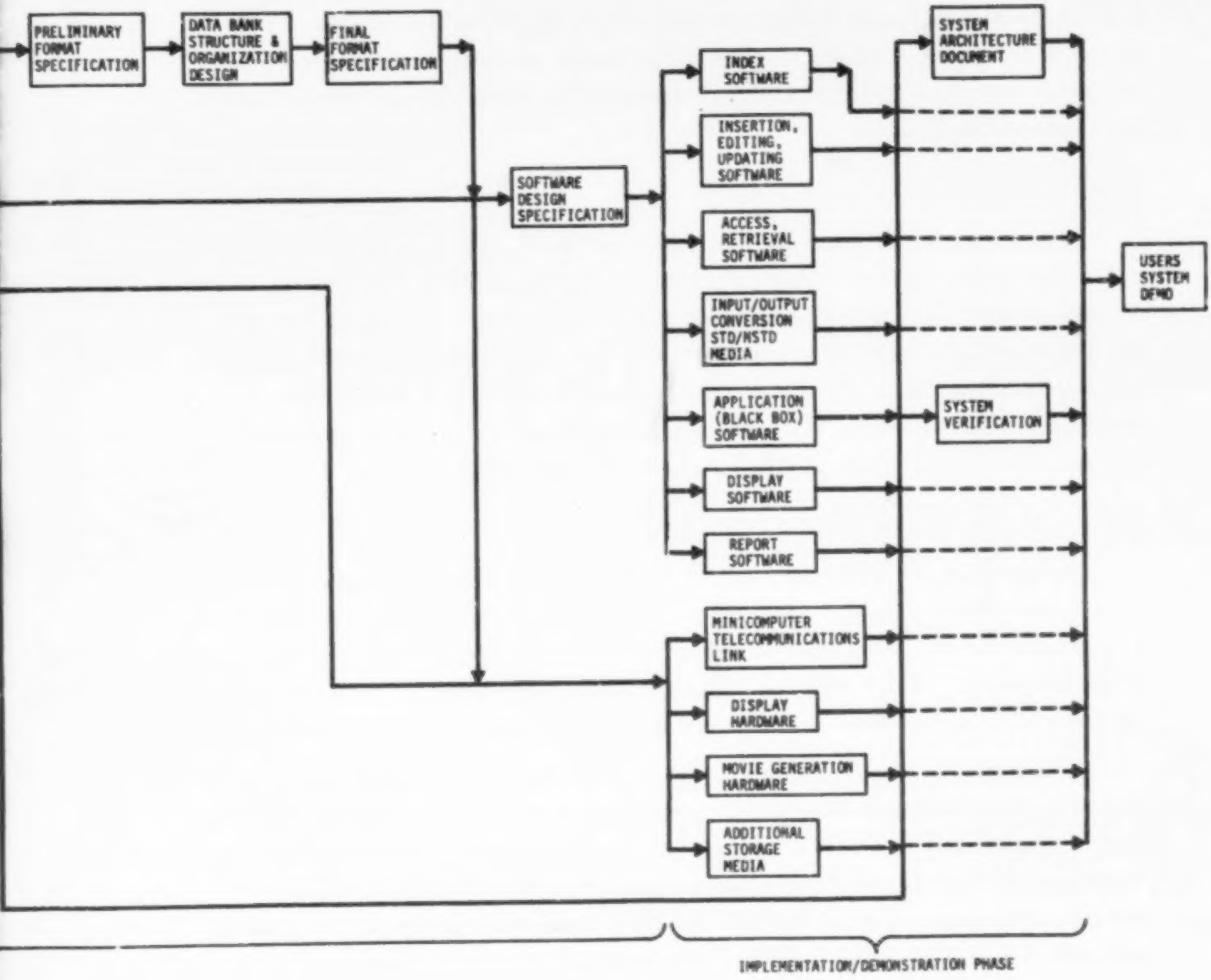

BEGIN DATA MANAGEMENT
SPECIFICATION OF RAPS DATA
SPECIFICATION OF DATA BASE CONTENT
PRELIMINARY SOFTWARE REQUIREMENTS
PRELIMINARY HARDWARE REQUIREMENTS
DATA QUALITY ASSURANCE SPECIFICATION
PRELIMINARY DATA FLOW REQUIREMENTS
DATA HANDLING AND PROCESSING CAPABILITY (INCLUDES RESOURCES) DEFINITION
FUNCTIONAL SOFTWARE SPECIFICATION
HARDWARE SPECIFICATION
GENERALIZED DATA FLOW DESIGN
PRELIMINARY FORMAT SPECIFICATION
DATA MANAGEMENT DESIGN PHASE

Figure 8. Flow Diagram of Data Management


PRELIMINARY FORMAT SPECIFICATION
DATA BANK STRUCTURE & ORGANIZATION DESIGN
FINAL FORMAT SPECIFICATION
SOFTWARE DESIGN SPECIFICATION
INDEX SOFTWARE
INSERTION, EDITING, UPDATING SOFTWARE
ACCESS, RETRIEVAL SOFTWARE
INPUT/OUTPUT CONVERSION STD/NSTD MEDIA
APPLICATION (BLACK BOX) SOFTWARE
DISPLAY SOFTWARE
REPORT SOFTWARE
MINICOMPUTER TELECOMMUNICATIONS LINK
DISPLAY HARDWARE
MOVIE GENERATION HARDWARE
ADDITIONAL STORAGE MEDIA
SYSTEM ARCHITECTURE DOCUMENT
SYSTEM VERIFICATION
USERS SYSTEM DEMO
IMPLEMENTATION/DEMONSTRATION PHASE

Data Management Effort

b

Plans for storage and user access of RAMS and upper air data may be obtained from Mr. Browning. Briefly, the data management system being implemented for RAPS allows an investigator to obtain RAMS data for any station, on any day, for any measured parameter. This is accomplished via the use of System 2000 data management language. At this writing turn around times for such request have not been specified, although availability in near real-time is desired by some principal investigators.

Recommendations

Two additions to planned data management operations are recommended. Firstly, it is recommended that pollutant distribution and wind field maps, based on RAMS and upper air soundings, be made available to RAPS participants following the special expeditionary periods. Maps for days of particular interest or, as appropriate to the investigation, maps for the entire length of certain expeditionary periods should be provided upon request of a RAPS principal investigator. The nature of the requests, i.e., number of maps, specific parameters, hourly summaries vs. daily summaries, etc., will depend upon the nature of the investigation and should be coordinated during planning of the field expeditionary exercise.

Secondly, it is recommended that pollutant distribution and wind field maps for several meteorological conditions be made available to RAPS participants as soon as the RAMS becomes operational. These maps would be prepared on a selective basis and would be representative of general meteorological conditions of interest to all investigations. For example meteorological conditions may be those which are: 1) typified by wind fields with flow from each of the four cardinal directions with associated pollutant distributions for a range of stability conditions observed; 2) representative of those situations which have a high expected frequency of occurrence for each month or season; and 3) considered to be examples of extreme situations, i.e., intense inversions, fumigation situations, extremely unstable air mass, etc. A more precise definition of the requirements and the means for sorting data by category should be coordinated among the RAPS participants to insure maximum usefulness of the information. Such maps would greatly enhance the planning of the special field expeditions, particularly in planning times of day, month or season for experiments, location of mobile equipment and types of measurements desired.

II. INTEGRATION AND SYNTHESIS OF THE RAPS ELEMENTS

The elements of the RAPS discussed in previous sections all focus on achievement of program objectives. It is the purpose of this section to discuss those aspects of the RAPS required to establish: (1) the logical relationship between RAPS elements and program objectives; (2) operational aspects of these elements as they relate to management factors; (3) the scheduling requirements; and (4) what elements are missing and/or need strengthening, if any.

Thus, presented in this section are the "pieces" of RAPS and their "products", as they relate to the principal program objectives--validated models. With these relationships established, operational procedures for the conduct of field expeditions are presented. This is then followed by the presentation of a Master Program Schedule.

LOGICAL RELATIONSHIPS BETWEEN RAPS ELEMENTS

The relationship between the various pieces of the RAPS and model development and evaluation can be illustrated by considering the schematic diagram in Figure 9.

Whatever the application chosen, air quality models relevant to RAPS focus on establishing the relationship between emissions and ambient air quality as defined by the existing or projected regulatory structure. With the exception of the regional heating or energetics (heat balance and radiative interaction) model, air quality represents a solution to the mass conservation for pollutant species S, which is given in mathematical shorthand by Equation (1) in Figure 9. Nomenclature used in Figure 9 may be found in Table 6. This expression must include boundary and initial conditions, as illustrated. In the case of sulfur, for example, total sulfur can be expressed in terms of gaseous components Sg and particulate components, Sp. That is S=Sg+Sp.

In a turbulent medium, such as the atmosphere, the trace pollutants fluctuate in concentration with variations in the fluid. For averaging over a given time (or over space), Equation (1) in Figure 9 can be rewritten with well

TABLE 6 NOMENCLATURE FOR FIGURE 9

S	concentration of pollutant
t	time
$\vec{v}$	wind velocity
D_s	molecular diffusivity of species S
K	eddy diffusivity coefficient
k	chemical rate constant
α	loss rate coefficient
E	emission rate
L	loss rate
S_T	total time derivative (dS/dt)
S_t	partial time derivative ($\partial S/\partial t$)
v	wind field
S_x	spatial derivative of S, ∇S
S_{xx}	Laplacian of S, $\nabla^2 S$
T	temperature
RH	relative humidity
$h\nu$	radiation as a function of frequency, ν
I	light intensity
Q	heat flux
z	vertical coordinate
x	horizontal coordinate
x_s	location of source S
z_s	height of source S
Δt	time interval of source measurement
v	volume of aerosol particle
n	particle size number density function
d_s	surface loss coefficient
C	corrosion rate
b_{scat}	integrated extinction coefficient for scattered light
b	lidar back scatter coefficient
H	mixing height

CONCEPTUAL INTEGRATION OF RAPS ELEMENTS

AIR QUALITY MODEL COMMON DENOMINATOR

THE MASS CONSERVATION LAW FOR SPECIES WITH CONCENTRATION S

(1) AT ANY INSTANT

$$\frac{dS}{dt} = \frac{\partial S}{\partial t} + \vec{v}\cdot\nabla S = D_s\nabla^2 S \pm kS^n - \alpha S ,$$

RATE OF CHANGE IN S FOLLOWING AIR PARCEL	=	RATE OF CHANGE IN S AT FIXED POINT	+	ADVECTION OF S BY WIND FIELD	=	MOLECULAR DIFFUSION OF S	±	CHEMICAL REACTION OF S IN AIR	-	LOSS OF S BY CLOUD PROCESSES

INITIAL CONDITION $S = S(\vec{x}, t_o)$ - INITIAL DISTRIBUTION OF S

BOUNDARY CONDITIONS $E = E(\vec{x}, t)$ - EMISSION RATE OF S

$L = L(\vec{x}, t)$ - LOSS RATE OF S AT SURFACE

(2) TURBULENT MEDIUM* AVERAGE OVERTIME INTERVAL AT A POINT

$$\frac{d\bar{S}}{dt} = \frac{\partial \bar{S}}{\partial t} + \bar{\vec{v}}\cdot\nabla\bar{S} = D_s\nabla^2\bar{S} - \nabla\cdot(\overline{u'S'} + \overline{v'S'} + \overline{w'S'}) \qquad |\pm k\bar{S}^n - \bar{\alpha}\bar{S}$$

(3) K THEORY ASSUMPTION

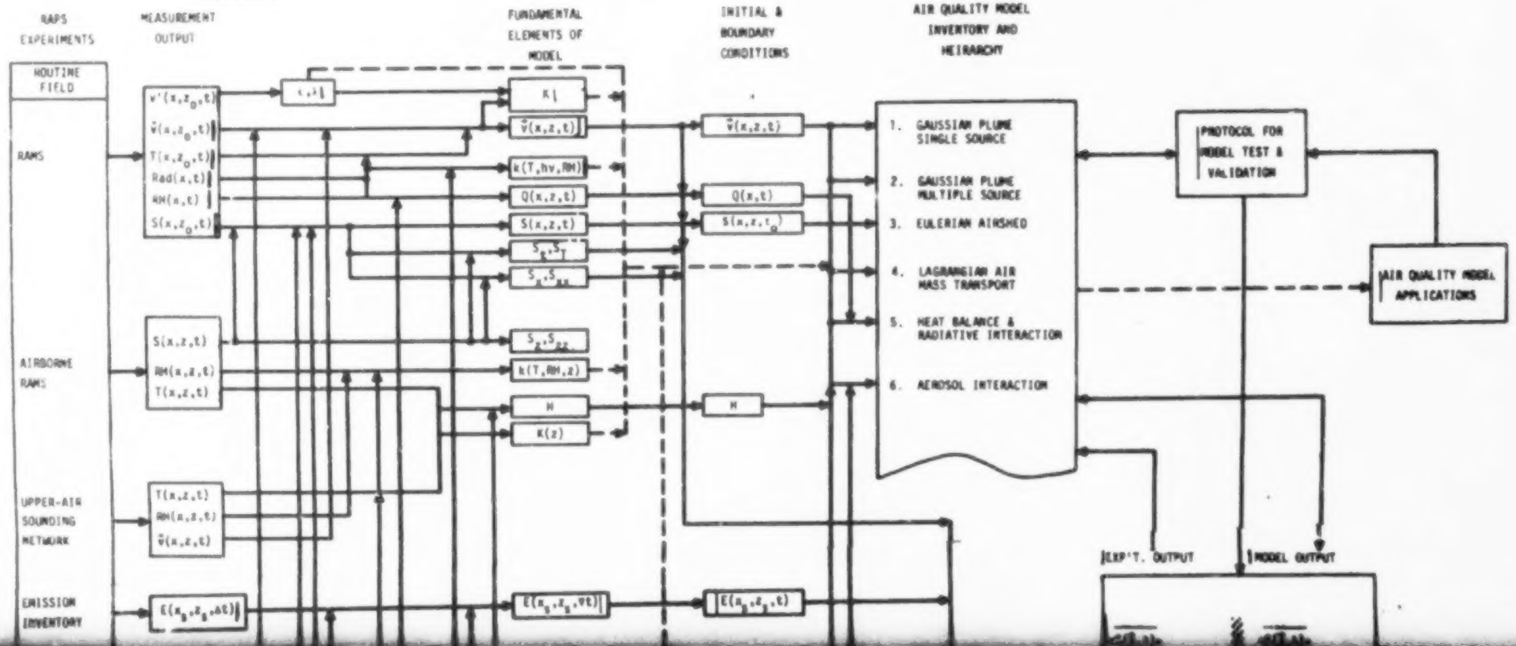
$$\frac{d\bar{S}}{dt} = \frac{\partial \bar{S}}{\partial t} + \bar{\vec{v}}\cdot\nabla\bar{S} = 0 \qquad \nabla\cdot K\nabla\bar{S} \qquad |\pm k\bar{S}^n - \alpha\bar{S}$$

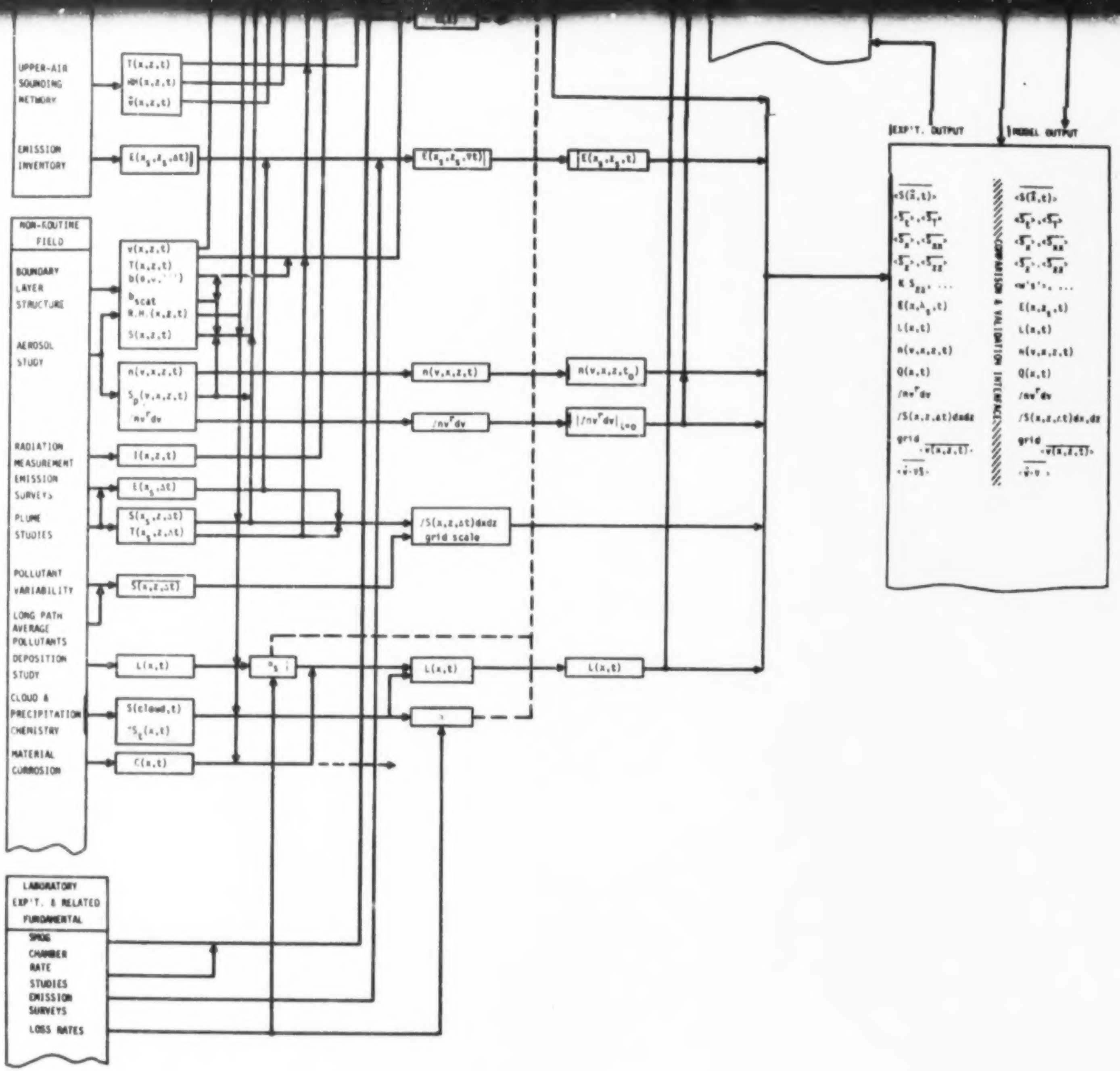
FUNDAMENTAL ELEMENTS OF RAPS

$$[S_T] = [S_t] + [V]\cdot[S_x] = [S_{xx}] \qquad |\mu\cdot[S] - [S]$$

$^*[K]\cdot \qquad |[k]\cdot \qquad [\alpha]\cdot$

- DIRECTLY CALCULATED FROM MEASURED PARAMETERS WITH NO ASSUMPTIONS
- DERIVED PARAMETERS BASED ON THEORY, LABORATORY, EXPERIENCE AND FIELD MEASUREMENTS


RAPS EXPERIMENTS
MEASUREMENT OUTPUT
FUNDAMENTAL ELEMENTS OF MODEL
INITIAL & BOUNDARY CONDITIONS
AIR QUALITY MODEL INVENTORY AND HEIRARCHY
ROUTINE FIELD
RAMS
AIRBORNE RAMS
UPPER-AIR SOUNDING NETWORK
EMISSION INVENTORY
v'(x,z_0,t)
v(x,z_0,t)
T(x,z_0,t)
Rad(x,t)
RH(x,t)
S(x,z_0,t)
S(x,z,t)
RH(x,z,t)
T(x,z,t)
T(x,z,t)
RH(x,z,t)
v(x,z,t)
E(x_s,z_s,Δt)
K
v(x,z,t)
k(T,hν,RH)
Q(x,z,t)
S(x,z,t)
S_t,S_T
S_x,S_xx
S_z,S_zz
k(T,RH,z)
H
K(z)
E(x_s,z_s,∇t)
v(x,z,t)
Q(x,t)
S(x,z,t_o)
H
E(x_s,z_s,t)
1. GAUSSIAN PLUME SINGLE SOURCE
2. GAUSSIAN PLUME MULTIPLE SOURCE
3. EULERIAN AIRSHED
4. LAGRANGIAN AIR MASS TRANSPORT
5. HEAT BALANCE & RADIATIVE INTERACTION
6. AEROSOL INTERACTION
PROTOCOL FOR MODEL TEST & VALIDATION
AIR QUALITY MODEL APPLICATIONS
EXP'T. OUTPUT
MODEL OUTPUT



UPPER-AIR SOUNDING NETWORK
EMISSION INVENTORY
T(x,z,t)
RH(x,z,t)
v(x,z,t)
E(x_s,z_s,Δt)
NON-ROUTINE FIELD
BOUNDARY LAYER STRUCTURE
AEROSOL STUDY
RADIATION MEASUREMENT
EMISSION SURVEYS
PLUME STUDIES
POLLUTANT VARIABILITY
LONG PATH AVERAGE POLLUTANTS
DEPOSITION STUDY
CLOUD & PRECIPITATION CHEMISTRY
MATERIAL CORROSION
v(x,z,t)
T(x,z,t)
b(θ,v,...)
b_scat
R.H.(x,z,t)
S(x,z,t)
n(v,x,z,t)
S_p(v,x,z,t)
∫nv^r dv
I(x,z,t)
E(x_s,Δt)
S(x_s,z,Δt)
T(x_s,z,Δt)
S(x,z,Δt)
L(x,t)
S(cloud,t)
S_ℓ(x,t)
C(x,t)
v_s
E(x_s,z_s,∇t)
n(v,x,z,t)
∫nv^r dv
∫S(x,z,Δt)dxdz grid scale
L(x,t)
λ
E(x_s,z_s,t)
n(v,x,z,t_0)
|∫nv^r dv|_{t=0}
L(x,t)
LABORATORY EXP'T. & RELATED FUNDAMENTAL
SMOG CHAMBER
RATE STUDIES
EMISSION SURVEYS
LOSS RATES
EXP'T. OUTPUT
MODEL OUTPUT
COMPARISON & VALIDATION INTERFACE
<S(x̂,t)>
<S_t>,<S_T>
<S_x>,<S_xx>
<S_z>,<S_zz>
K S_zz, ...
E(x,λ_s,t)
L(x,t)
n(v,x,z,t)
Q(x,t)
∫nv^r dv
∫S(x,z,Δt)dxdz
grid <v(x,z,t)>
<v̂·∇S>
<S(x̂,t)>
<S_t>,<S_T>
<S_x>,<S_xx>
<S_z>,<S_zz>
<w's'>, ...
E(x,z_s,t)
L(x,t)
n(v,x,z,t)
Q(x,t)
∫nv^r dv
∫S(x,z,Δt)dx,dz
grid <v(x,z,t)>
<v̂·∇ >

Figure 9. Conceptual Integration of RAPS Elements

b

known approximations as Equation (2). Here the time averaged pollutant concentration $\overline{S}$ relates to transport and source or loss contributions in a manner analogous to the expression for the instantaneous concentration, S. Formally, Equation (2) also could be written in terms of a spatial average $\langle S \rangle$ or a spatial/temporal average $\langle \overline{S} \rangle$, with suitable assumptions.

Existing air quality models simplify Equation (2) of Figure 9 further by disregarding molecular diffusion and simplifying the eddy-diffusion terms with the K-theory approximation, as indicated in Equation (3)

Accepting the K-theory model on a conceptual basis, the fundamental elements of the RAPS can be identified with the various terms of the mass conservation equation. These elements are classed as (1) directly calculated with no physical assumptions, and (2) those derived parameters based on theory, laboratory experience or the history of previous field study parameterizations. Within this framework, the various elements of the RAPS can be linked to the model heirarchy as shown in Figure 9.

On the left side, the RAPS currently planned experiments are listed. These have been classified as routine and non-routine field studies, and laboratory or other fundamental studies. The field programs generate and list measurement outputs. Fundamental elements of the models are deduced from the measurements. These, in turn, are used to establish the inputs and the initial boundary conditions for the model heirarchy. Through the exercise of the model inventory and associated development work, the experiment (measurement) output is interfaced with the model output for comparison and validation. This interface is defined by the protocal for test and validation. The protocol must be laid out on a rational basis and it must take into account model applications, application requirements and the known limitations of the individual models.

The heart of the RAPS experiment achievements center around the intercomparison module shown conceptually at the middle right hand side of Figure 9. Although no explicit mention is made of data management, it should be obvious that it is related to virtually every element of the program

OPERATIONAL PROCEDURES FOR THE CONDUCT OF THE RAPS FIELD EXPEDITIONS

The relatively large number of RAPS participants, along with their varied interests and activities, requires that standardized operational procedures be established. It is therefore recommended that all field expeditions conform to a schedule which consists of the following phases: 1) an experimental design phase at the end of which its approval from EPA/RAPS management is obtained; 2) a preparation phase; 3) a measurement or an experiment phase; and 4) a data validation and analysis phase. The duration of any phase for a particular expedition may be different. Discussions with virtually all RAPS investigators lead us to believe this recommendation is acceptable. Not only will this make program control more possible, it also affords management the opportunity to maintain and disseminate efficiently to all participants information vital to the conduct of an informed program.

Elements of Field Expedition

Figures 10 and 11 depict logic flow charts of the elements comprising each phase. These figures are intended to stand alone and therefore do not require extensive discussion; however, for purposes of completeness a discussion follows.

At the outset it should be recognized that not all elements are necessarily applicable. As indicated in Figure 10 the experimental design begins with two activities occurring in parallel, the identification of model requirements and an aerometric evaluation of the St. Louis AQCR with respect to the particular expedition being proposed. This might include consideration and evaluation of available aerometric data from RAMS, the upper air sounding network (UASN), the aerial monitoring system (AMS) and the air monitoring networks of St. Louis City, St. Louis County, Illinois and Missouri. Consideration of these data, coupled with the identification of model requirements which are consistent with established RAPS objectives, enables development of criteria for when and where the expedition should be conducted. For the candidate locations and periods of interest,

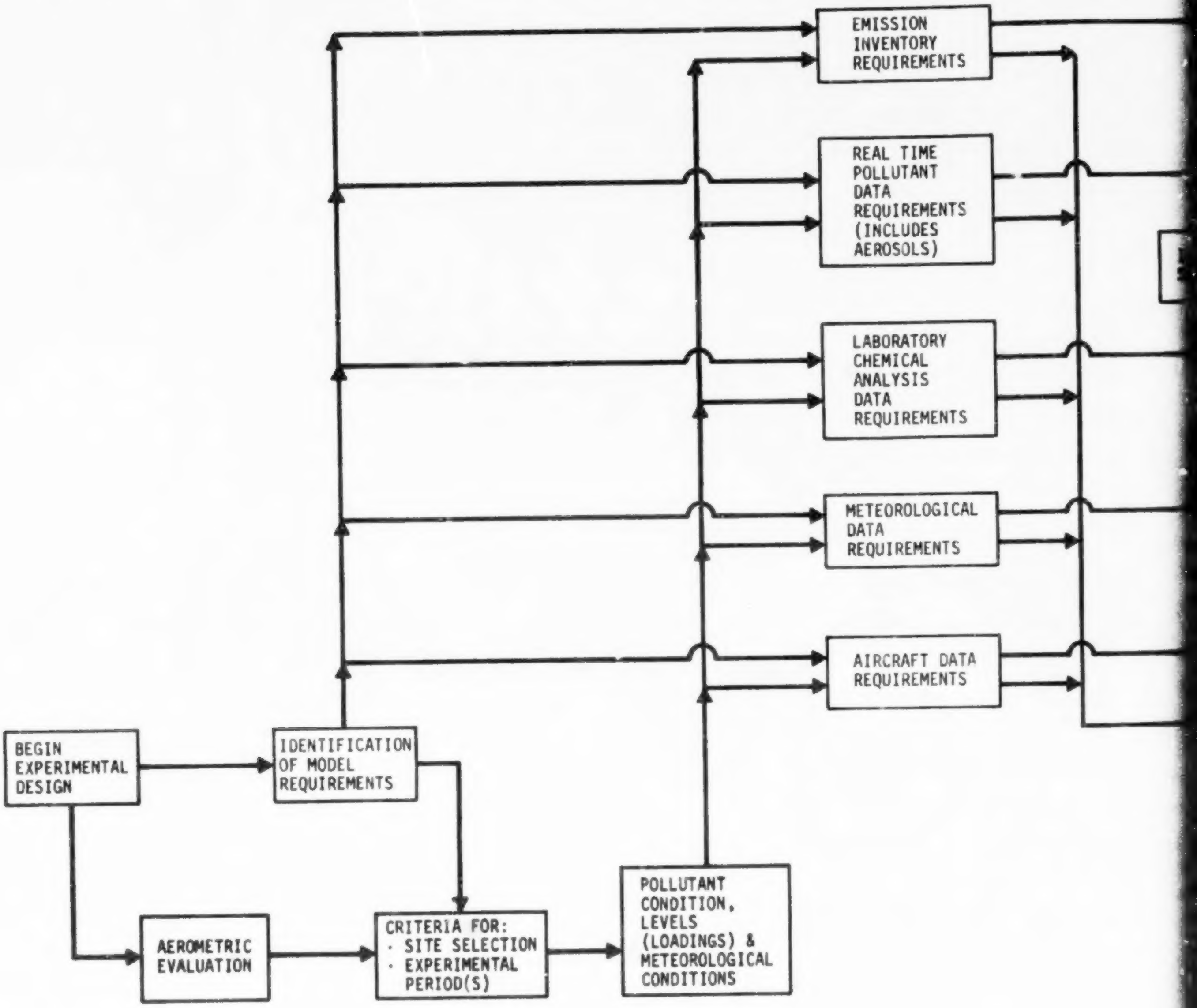
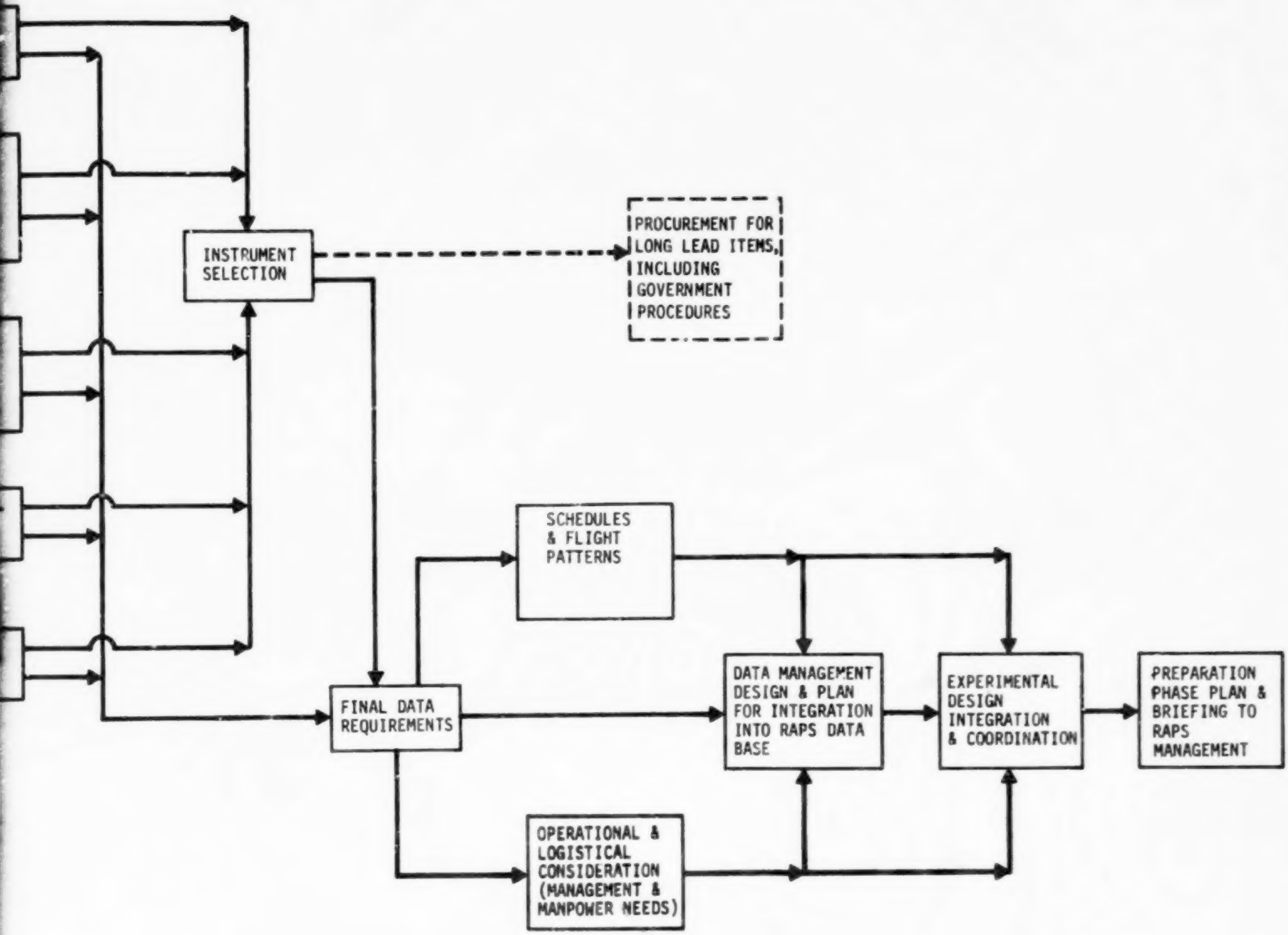

EMISSION INVENTORY REQUIREMENTS
REAL TIME POLLUTANT DATA REQUIREMENTS (INCLUDES AEROSOLS)
LABORATORY CHEMICAL ANALYSIS DATA REQUIREMENTS
METEOROLOGICAL DATA REQUIREMENTS
AIRCRAFT DATA REQUIREMENTS
BEGIN EXPERIMENTAL DESIGN
IDENTIFICATION OF MODEL REQUIREMENTS
AEROMETRIC EVALUATION
CRITERIA FOR:
· SITE SELECTION
· EXPERIMENTAL PERIOD(S)
POLLUTANT CONDITION, LEVELS (LOADINGS) & METEOROLOGICAL CONDITIONS

Figure 10. Flow Chart of Exp

a


INSTRUMENT SELECTION
PROCUREMENT FOR LONG LEAD ITEMS, INCLUDING GOVERNMENT PROCEDURES
SCHEDULES & FLIGHT PATTERNS
FINAL DATA REQUIREMENTS
DATA MANAGEMENT DESIGN & PLAN FOR INTEGRATION INTO RAPS DATA BASE
EXPERIMENTAL DESIGN INTEGRATION & COORDINATION
PREPARATION PHASE PLAN & BRIEFING TO RAPS MANAGEMENT
OPERATIONAL & LOGISTICAL CONSIDERATION (MANAGEMENT & MANPOWER NEEDS)

low Chart of Experimental Design Phase

meteorological and pollutant conditions are examined. A number of data requirements may then be specified for the particular expedition. Following instrument selection, procurement arrangements (as well as the final specification of data requirements) would be initiated. Consideration of the operational and logistical aspects (along with the development of candidate measurement schedules and patterns) and requirements from the RAPS St. Louis facility, leads to the design of a data management plan.

The nature of the data management plan requires additional comment. It should include a description of the proposed data flow, the medium upon which the data are collected, EPA computer use requirements, RAPS-St. Louis computer use requirements and a quality control plan.

The completion of the data management plan logically is followed by the development of an integrated experimental design that contains a schedule to completion, which is to be forwarded to RAPS management. Subsequent to this a briefing may be deemed necessary.

The duration of the entire experimental design may take a few days to a few weeks. Regardless of the time, it is the most effective means to communicate the plans of the investigator, not only to RAPS management, but also to other participants. As these plans can be expected to change, RAPS management can be kept informed, and all the benefits of this communication disseminated to the rest of the program participants. If plans for support from Rockwell are required, Rockwell may also be given advance notice along with copies of the relevant design elements.

With completion of the Experimental Design Phase, a planned field expedition enters the Preparation Phase. Figure 11 depicts the logic flow charts for this activity. For the most part, this diagram also stands alone. It should be pointed out however, that both preliminary data processing plans as well as any required exploratory measurements which would further advance the expedition would be started immediately.

Moreover, if Rockwell support is required during the expedition, there should be sufficient time to allow for participation in personnel training.

Obviously the nature of the measurement and data analysis phases cannot be discussed in any detail; however, as demonstrated in the discussion of the Master Program Schedule, every effort must be made to get tabulated, if not analyzed, valid data into the RAPS Data bank as soon as possible.

Management Utilization of Experiment Designs

The delivery of properly developed Experimental Designs (ED) will provide RAPS management with a great deal of information designed to maintain up-to-date program status. It is the purpose of this section to indicate some of the uses.

The ED will obviously specify who the participants are, what they will be doing, where they will be doing it, when they will be doing it and with what they will be doing it. In addition, coordination requirements with the RAMS, UASN, AMS, the RAPS St. Louis facility, and other field expeditions will be indicated. Finally, the media upon which all data are collected can be inventoried and evaluated in advance against available resources.

All of these data can be collated and presented in easily maintainable matrices. Thus, a number of hardware allocation matrices (one each for mobile units, trailers, aircraft, tracers, etc.) can be maintained, which keeps track of when and where a particular unit is to be used and who is responsible for the unit. A RAMS/Field Expeditionary utilization matrix can also be developed and maintained which indicates what stations are to be used, by whom, when the users intend to be there and what are their station requirements. A matrix indicating which Field Expeditions require data from the RAMS, UASN and AMS can be maintained. Finally, a Field Expeditionary coordination matrix can be developed and maintained which indicates which investigators wish to coordinate their activities either via measurement systems, data exchange, site location, etc.

MASTER PROGRAM MILESTONE SCHEDULE

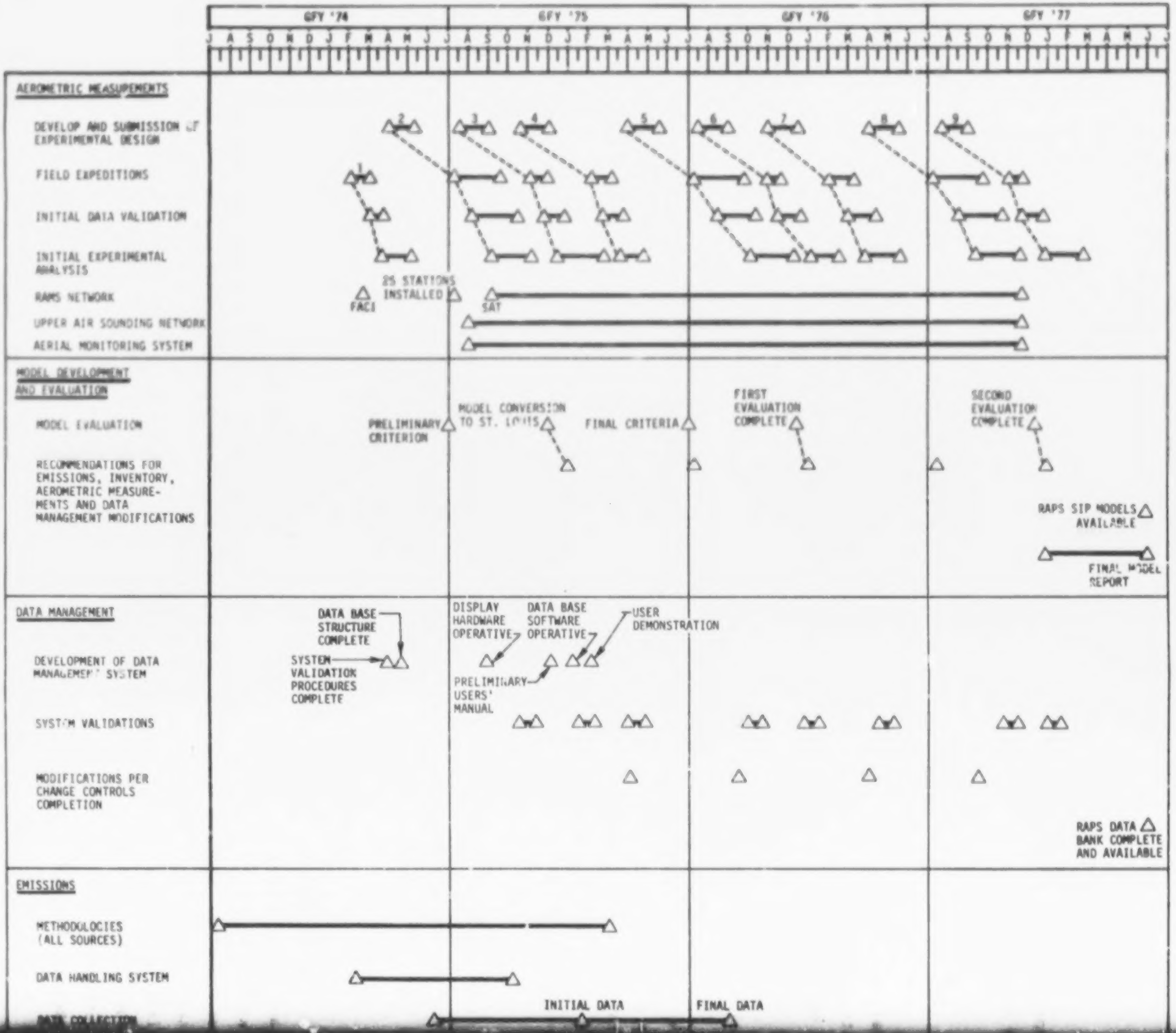
In previous sections of this report the logical development and relationships of the RAPS elements have been presented. Integration of these elements with time included is best accomplished through the use of a Master Program Milestone Schedule.

As indicated earlier, the RAPS is viewed as being comprised of five major tasks: 1) a Model Development and Evaluation Task, 2) an Aerometric Measurement Task; 3) an Emission Inventory Task: 4) a Data Management Task; and 5) a Program Management Task. Whereas the plan proposed herein places the Model Development and Evaluation Task with the overall guidance in the technical sense, it is the Program Management Task which provides the overall guidance in the timing and resource sense in order to comply with the RAPS objectives on schedule and within budget.

A master milestone chart for these five tasks is presented in Figure 12. Only those specific events (milestones) which are presently considered as important reference points in meeting the objectives have been included.

Program Management Task

Starting at the bottom of Figure 12, it is noted that the Program Management Task consists of five parts. Short term and annual progress is monitored via approvals of experimental designs, kick-off meetings just prior to the periods of field expeditionary activities and annual status reports of the principal investigators which are phased (dotted lines) with the annual critical RAPS review meetings. Program direction is achieved through the experimental design reviews and program control meetings. Moreover, as previously indicated, program status of the important field expeditionary program is maintained via the experimental designs and is


GFY '74
GFY '75
GFY '76
GFY '77
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J
AEROMETRIC MEASUREMENTS
DEVELOP AND SUBMISSION OF EXPERIMENTAL DESIGN
FIELD EXPEDITIONS
INITIAL DATA VALIDATION
INITIAL EXPERIMENTAL ANALYSIS
RAMS NETWORK
UPPER AIR SOUNDING NETWORK
AERIAL MONITORING SYSTEM
1
2
3
4
5
6
7
8
9
FACI
25 STATIONS INSTALLED
SAT
MODEL DEVELOPMENT AND EVALUATION
MODEL EVALUATION
RECOMMENDATIONS FOR EMISSIONS, INVENTORY, AEROMETRIC MEASUREMENTS AND DATA MANAGEMENT MODIFICATIONS
PRELIMINARY CRITERION
MODEL CONVERSION TO ST. LOUIS
FINAL CRITERIA
FIRST EVALUATION COMPLETE
SECOND EVALUATION COMPLETE
RAPS SIP MODELS AVAILABLE
FINAL MODEL REPORT
DATA MANAGEMENT
DEVELOPMENT OF DATA MANAGEMENT SYSTEM
SYSTEM VALIDATIONS
MODIFICATIONS PER CHANGE CONTROLS COMPLETION
DATA BASE STRUCTURE COMPLETE
SYSTEM VALIDATION PROCEDURES COMPLETE
DISPLAY HARDWARE OPERATIVE
DATA BASE SOFTWARE OPERATIVE
USER DEMONSTRATION
PRELIMINARY USERS' MANUAL
RAPS DATA BANK COMPLETE AND AVAILABLE
EMISSIONS
METHODOLOGIES (ALL SOURCES)
DATA HANDLING SYSTEM
DATA COLLECTION
INITIAL DATA
FINAL DATA

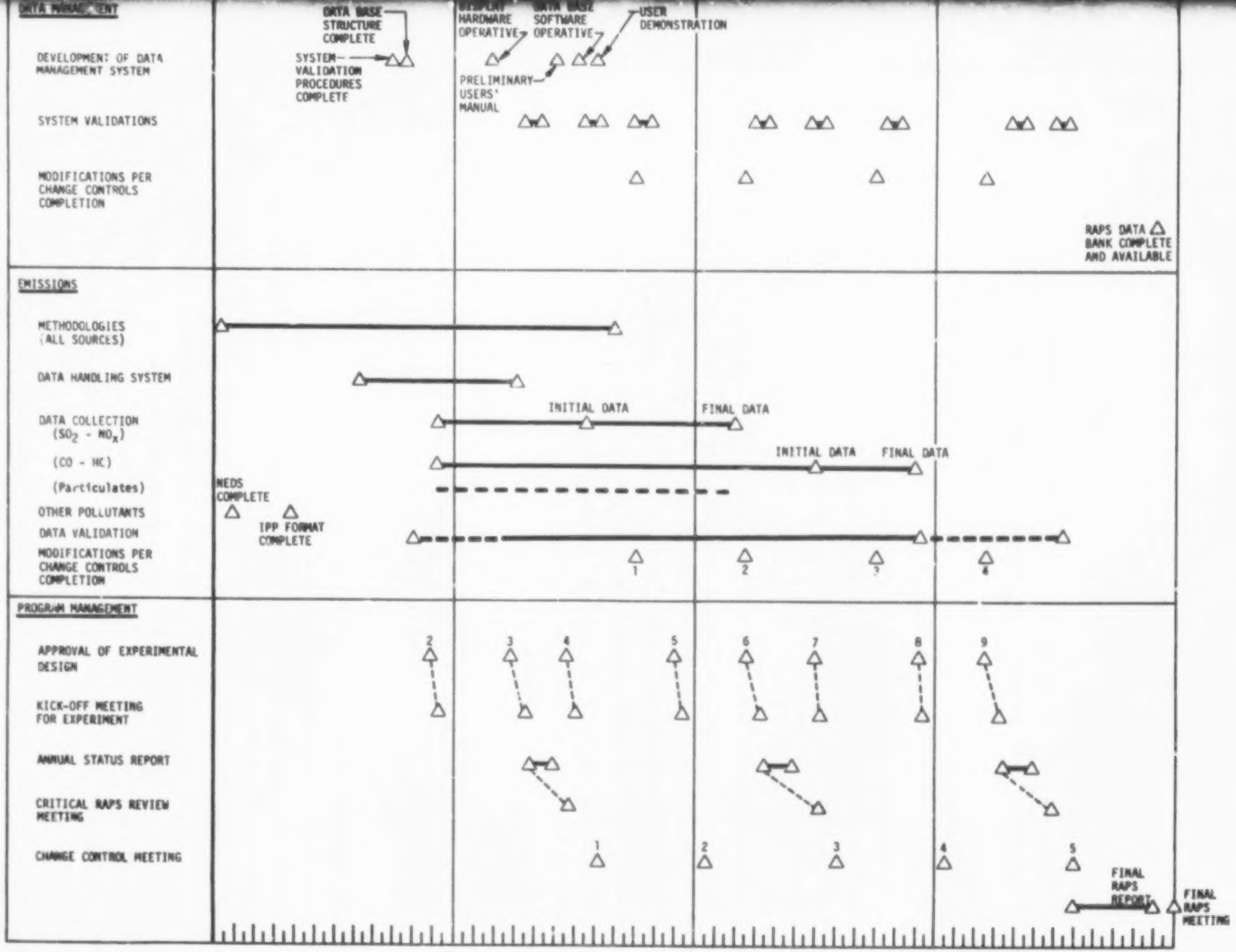


Figure 12. Master Milestone Chart

the responsibility of the Field Director. The overall status of the RAPS is formally communicated to the participants through the critical RAPS review meetings. Responsibility for overall RAPS final reporting lies with the Program Manager. Although the scope of the Program Management task as recommended is deemed adequate, it is not considered excessive for an effort of the magnitude and complexity of the RAPS.

Model Development and Evaluation Task

The model evaluation (and evaluation criteria) and the recommendations to the emissions, measurement and data management task constitute the key milestones of this effort. The former are phased with the RAPS critical meetings while the latter are phased with the program control change meetings of the PM task. The need for early consideration for establishing evaluation criteria is clearly established by examination of the timing. In fact, this should be considered a critically important item at this time.

Aerometric Measurement Task

The organization of this task assumes that the recommendation made earlier concerning the adoption of specified period for intensive field expeditions was accepted. Thus, the numbering in Figure 12 denotes the first such period, the second such period, etc. The field expeditionary programs begin with the development and submission of experimental designs and, following the measurement period, pass through an initial data validation and experimental analysis phase. Two expeditionary activities have been conducted without formal experimental designs. While the first was small and consisted of only two investigators, the second was quite large and traumatic in the early preparation activities due to the lack of adequate communication. The second activity constitutes a first-cut at data collection and analysis. With the RAMS systems acceptance test (SAT) completed in early October, formal operations begin; however, as early as July, partial operations will begin.

The specific nature of the field expeditions planned for each expeditionary period are indicated in Figure 13. The nature of these studies was discussed on Page 18, while their relationship to the RAPS "product" is indicated in Figure 9. In Figures 14, 15, and 16 are indicated the specific hardware systems planned for the various expeditionary periods. Thus, it is seen that the summer period is scheduled to have approximately 12 mobile units and 9 aircraft taking measurements in the St. Louis AQCR. Furthermore, it is seen that tracer studies begin in the summer '74, with more intensive activities beginning in the summer '75 period.

Data Management Task

The Data Management(DM) Task consists (cf. Figure 12) of the development of the DM system, system (field expeditionary) validations, and operational/procedural modifications. The system validations efforts are phased with the initial data validation efforts of the aerometric measurements task and constitutes a machine validation of the field experiment data. Operational/procedural modifications are phased with the program change controls as derived from the PM task.

Emissions Inventory Task

The first four broad segments of the emission inventory task represent a condensation of the schedule presented in Figure 5 with the one exception of the modifications which are, once again, phased with the program change controls.

As indicated by the schedule, emission data from the data collection activity will not be available until late in the program. It should be noted that the NEDS inventory can be used for initial model testing; however, critical delays (depending upon the vagaries of the industrial and local authorities as to data attainability) in model evaluation and validation are possible. At this writing cooperation by local industry appears to be favorable.

	Field Expedition Periods								
Field Tasks	1	2	3	4	5	6	7	8	9
Boundary Layer Study	x	x	x	x	x	x	x	x	x
Energy Budgets Study		x	x	x	x	x	x	x	x
Aerosol Studies	x	x	x	x	x		x	x	
Point Source Plume		x	x	x	x	x	x	x	x
Urban Plume	x	x	x	x	x	x	x	x	x
Surface Deposition		x	x	x	x	x	x	x	x
Pollutant Variability		x	x	x	x	x	x	x	x
Bag Irradiation		x			x			x	
Measurement Technology		x	x	x	x	x	x	x	x

Figure 13. Field Expeditions Planned for Duration of the RAPS

	Field Expedition Periods								
Mobile Unit Description	1	2	3	4	5	6	7	8	9
General Electric Trailer 8' x 20', McClenny/Chaney		x			x				
EPA Motor Home (Lincoln Lab), McClenny/Chaney		x			x	?	?	x	?
Meteorology Panel Van Elroy	x	x	x	x	x	x	x	x	x
Mobile Lidar Truck McElroy/Peterson		x	x	x	x	x	x	x	x
U. of Wyoming Mobile Unit #1, McElroy		x			x				
U. of Wyoming Mobile Unit #2, McElroy		x			x				
BNL Mobile Unit Newman		x	?	x	x		x	x	
Moveable Aerosol Lab Wilson	x	x	x	x	x		x	x	
Winnebago Kopczynski		x	x	x	x	x	x	x	x
Mobile Tower Wilson		x		?	?		?	?	
Whitby's Mobile Unit Wilson				x	x		x	x	
Scott Office Trailer 35', Wilson (Optical Instr.)		x		?					

Figure 14. Hardware Allocation (by Field Expedition Period) Matrix

	Field Expedition Periods								
Aircraft	1	2	3	4	5	6	7	8	9
Helicopter (Fostaire or equiv), McElroy	x	x	x	x	x	x	x	x	x
Penn State Fixed Wing (or equiv), McElroy/ Peterson		x	x	x	x	x	x	x	x
Las Vegas C-45 or B-26, Peterson		x	x	x	x	x	x	x	x
U. of Wyoming Queen Air, McElroy		x	x		x				
NCAR Fixed Wing McElroy		x							
MRI Fixed Wing Wilson		x	?	x	x		x	x	
BNL Fixed Wing Newman		x	?	x	x		x	x	
Las Vegas Helicopter #1, Evans		x	x	x	x	x	x	x	x
Las Vegas Helicopter #2, Evans		x	x	x	x	x	x	x	x
Las Vegas Helicopter #3, Evans		x	x	x	x	x	x	x	x

Figure 15. Aircraft Allocation (by Field Expedition Period) Matrix

	Field Expedition Periods								
Tracer Description	1	2	3	4	5	6	7	8	9
SF6, BNL Newman		x	?	x	x		x	x	
FP McElroy, Pooler					x	x	x	x	x
SF6 McElroy, Pooler					x	x	x	x	x
Freons McElroy, Pooler, Dickson					?	x	x	x	x

Figure 16. Tracer Allocation (by Field Expedition Period) Matrix

III. SUMMER 1974 FIELD EXPEDITIONARY EXERCISE

The summer '74 Field Expeditionary Exercise will constitute by far the largest RAPS activity to date. More than twelve intensive activities are planned to begin in late July and continue through most of August. A few studies will run through mid-September.

One of the authors spent approximately seven weeks at the NERC, RTP, working with investigators and other RAPS participants to develop plans for the summer activities. Although experimental designs were necessarily brief, through the use of questionnaires and extensive personal discussions, sufficient information was gathered to prepare the schedule of activities for the summer period indicated in Figure 17. Activities were planned such that the majority of the effort is to be expended in August.

The field expeditionary coordination matrix for the summer period is presented in Figure 18. The matrix identifies those investigators who desire coordination in the conduct of joint experiments, in the sharing of instruments or in performing joint data analysis. The media upon which the data will be collected for expedition is shown in the matrix of Figure 19. By developing a Field Expeditionary/Routine Measurement Coordinator matrix (shown in Figure 20), those activities which are interfaced with the RAMS, UASN, AMS and EPA/RAPS St. Louis facility are easily displayed. For those expeditions requiring RAMS use, the specific site is given in the RAMS Station/Field Expeditionary Utilization Matrix in Figure 21. The matrices in Figures 18-21 should allow the Field Director to monitor continuously the summer '74 activities

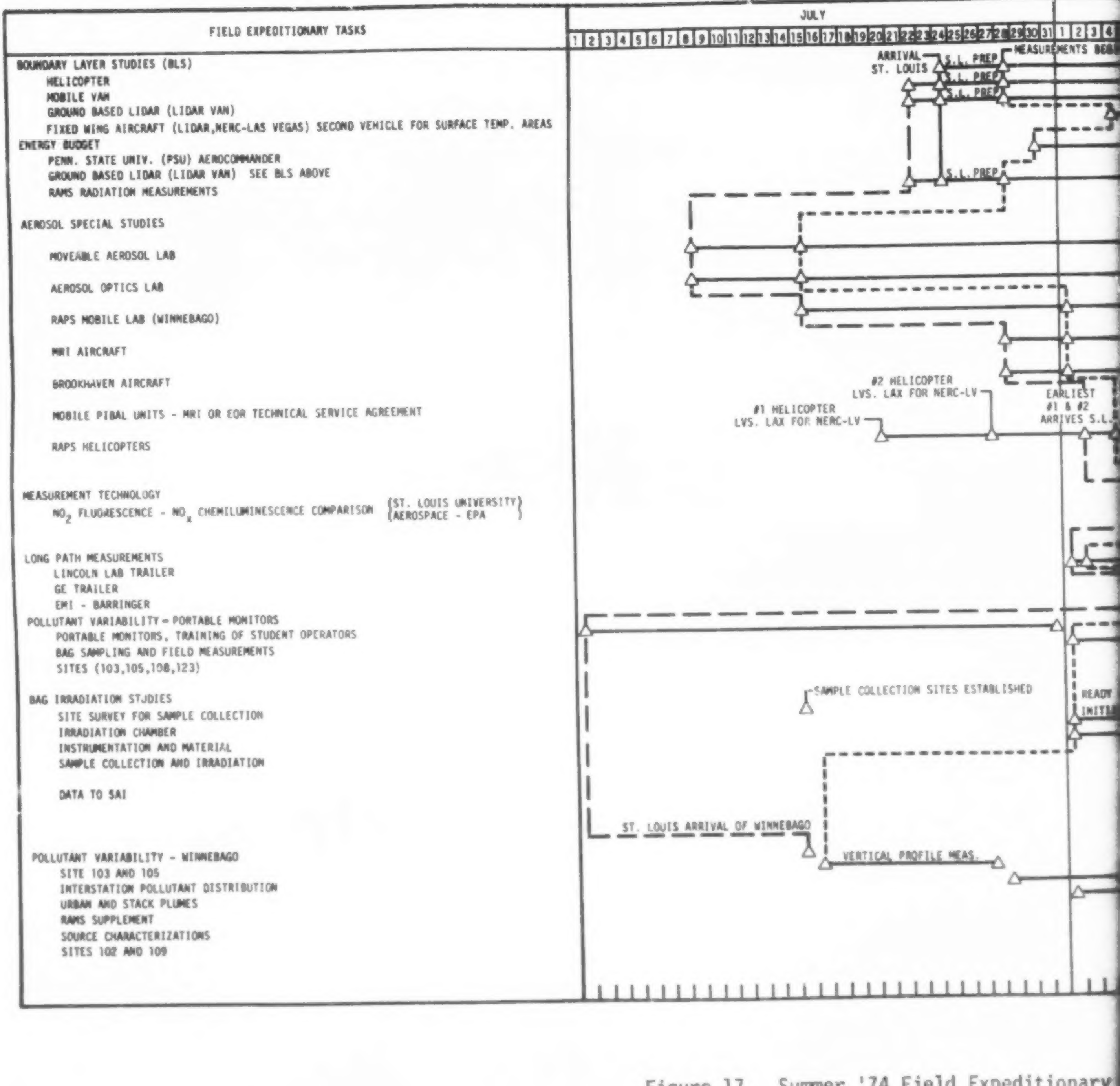
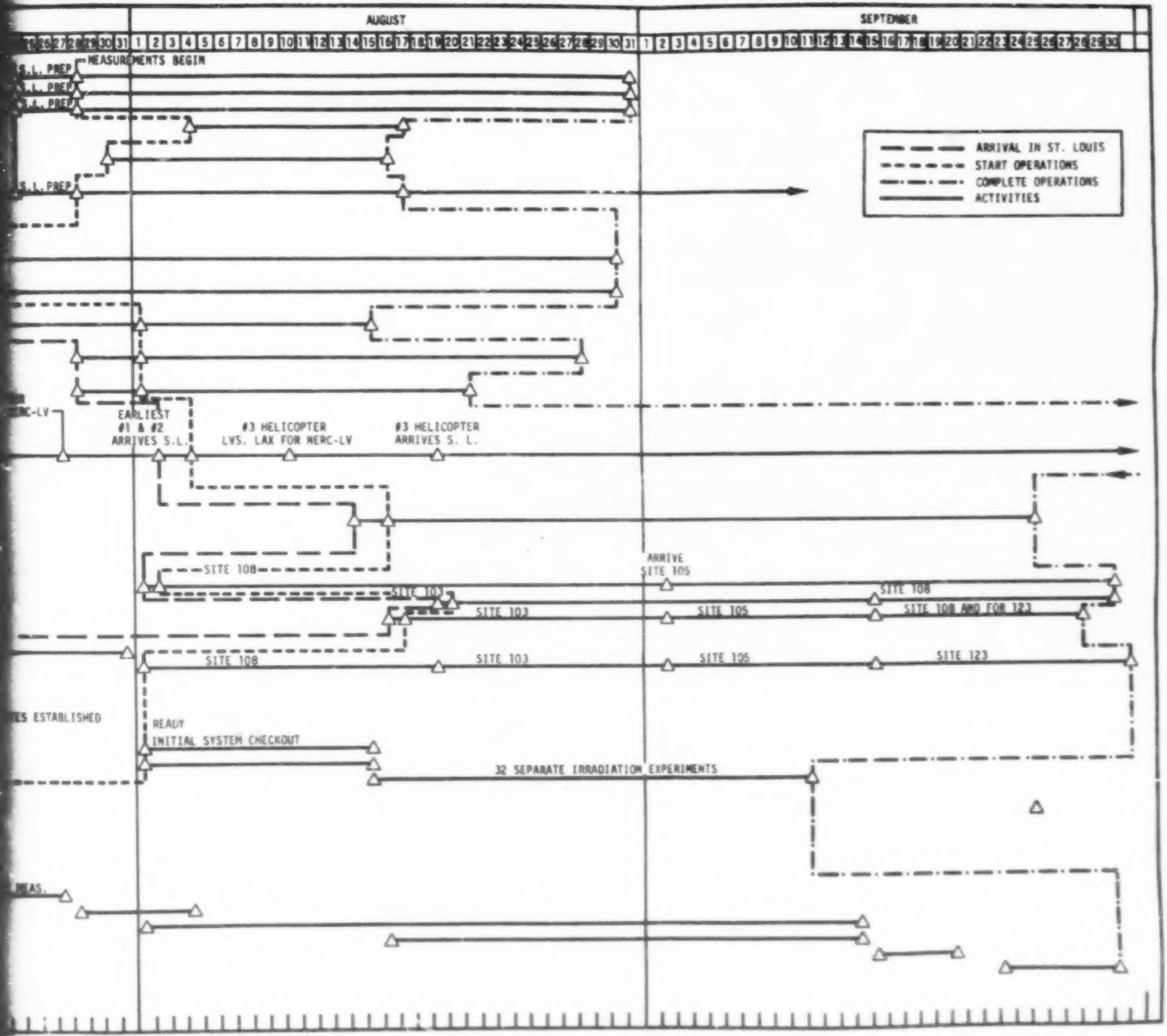


Figure 17. Summer '74 Field Expeditionary

a



Expeditionary Schedule (Field Expedition #2)

b

	BLS	EB	PSPTS	PSPS	UPS	ACS	PV	LMP	PMV	METROMEX	NASA LANGLEY
Boundary Layer Struc. (BLS) McElroy		x				x			x	x	
Energy Budget (EB) Peterson/McElroy	x					x		x		x	x
Point Source Plume Transformation Study L. Newman (PSPTS)				x	x						
Point Source Plume Study (PSPS) Wilson/Blumenthal			x		x	x					
Urban Plume Study (UPS) Wilson/Husar/Blumenthal			x	x		x					
Aerosol Characterizatio Study (ACS) Wilson/Durham	x	x	x	x	x						
Pollutant Variability (PV) McClenny/Chaney									x		
Long Path Measurements (LPM) McClenny/Chaney		x									
Pollutant Mapping & Variability (PMV) Kopczynski	x						x	x			
METROMEX	x	x									

Figure 18. Summer '74 Field Expeditionary Coordination Matrix (Expedition #2)

RAPS MEASUREMENT ELEMENT	STANDARD TAPE	NON-STANDARD TAPE	PAPER TAPE	CARDS	FORMS IN CARD IMAGES	STRIP CHART	JOURNALED DA.	SPECIFY OTHER
RAMS	x							
METEOROLOGICAL SOUNDING NETWK.								CHARTS
RAMS VERTICAL EXTENSION	x							
CAMP STATION	x							
G. E. TRAILER	x							
EPA MOTOR HOME (LINCOLN LAB)	x							
METEOROLOGY PANEL VAN						x		
MOBILE LIDAR TRUCK	x							POLAROID FILM
U. WYOMING UNIT #1						x		
U. WYOMING UNIT #2						x		
B.N.L. MOBILE UNIT						x		
MOVEABLE AEROSOL LAB	x			x	x	x	x	
WINNEBAGO		x				x	x	
MOBILE TOWER		x						
SCOTT OFFICE TRAILER		x						
FOSTAIRE (or equiv) HELICOPTER						x		
PENN STATE FIXED WING	x							
U. WYOMING QUEEN AIR	x							
NCAR FIXED WING	x							
MRI FIXED WING		x						
BNL FIXED WING						x		

Figure 19. Summer '74 RAPS Measurement Element Data Classification Matrix

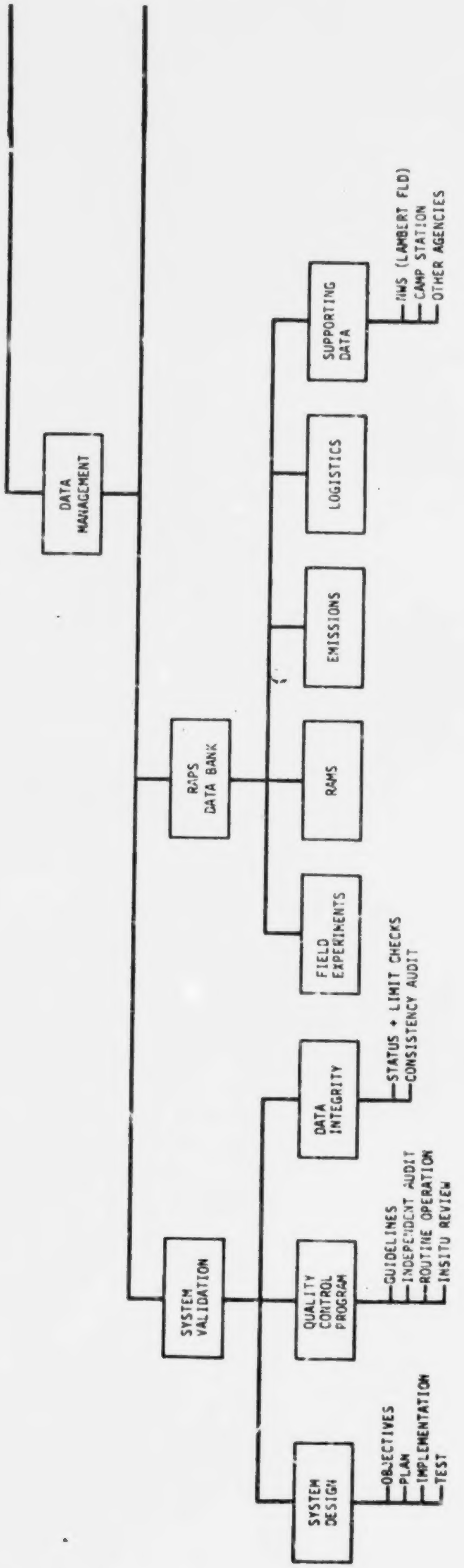
Special Field Expedition	RAMS	Upper Air Sounding Ntwk	Air Monitoring System	Central Facility
Boundary Layer Structure (McElroy)		x	x	x
Energy Budget (Peterson/McElroy)	x			x
Point Source Plume Transformation Study (Newman)		x		
Pollutant Variability (McClenny/Chaney)	x			x
Long Path Measurements (McClenny/Chaney)	x			x
Pollutant Mapping (Kopczynski)	x	x	x	x
METROMEX		x		
Bag Irradiation				x
Urban Plume Study (Wilson/Husar/Blumenthal)	x	x	x	x
Aerosol Characterization Study (Wilson/Durhan)	x	x		x

Figure 20. Summer '74 Field Expeditionary Measurement Coordination Matrix

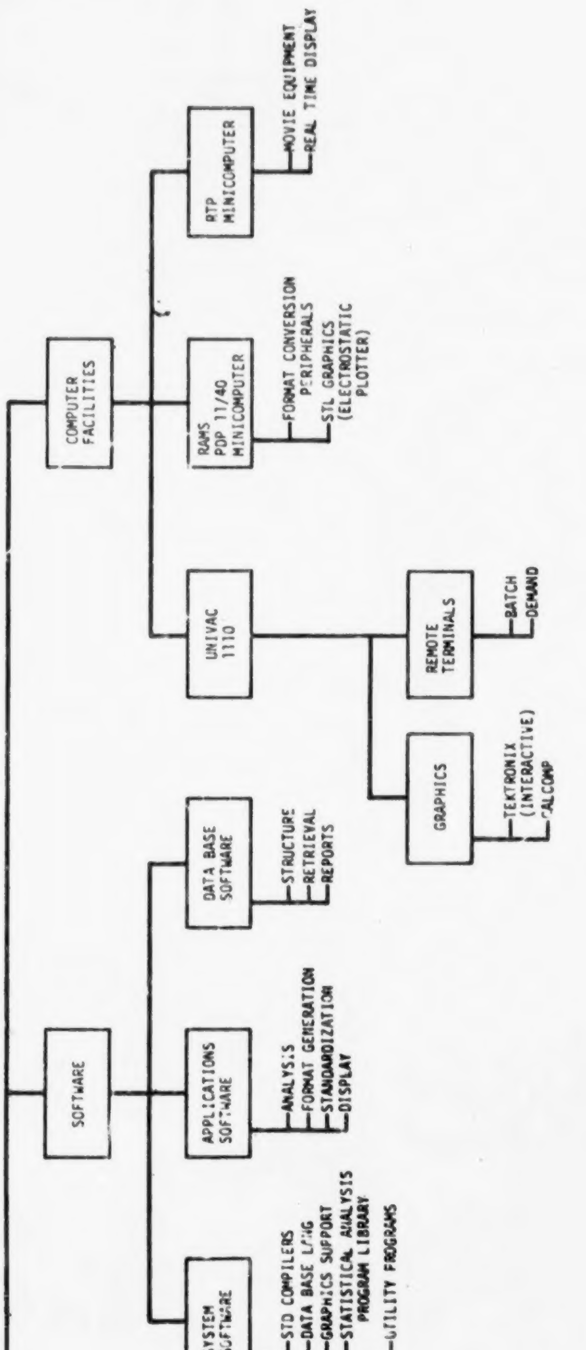
RAMS Station Numbers	Field Expeditionary Periods							
	2	3	4	5	6	7	8	9
101								
102	G. C. Bag Samples							
103	E.B. (R) P.V. G.C. Bag Samp		E.B. (R)	E.B. (R) P.V. L.P.	P.V. L.P.	E.B. (R) P.V. L.P.	E.B. (R) P.V. L.P.	
104								
105	E.B. (R) (HF) P.V.L.P. G.C. Bag Samp	E.B. (HF)	E.B. (R) (HF)	E.B. (R) (HF) P.V. L.P.	E.B. (HF)	E.B. (HF) (R) P.V. L.P.	E.B. (HF) (R) P.V. L.P.	E.B. (HF)
106	G.C. Bag Samp							
107								
108	E.B. (R) P.V. L.P. G.C. Bag. Samp.		E.B. (R)	E.B. (R) P.V. L.P.		E.B. (R) P.V. L.P.	E.B. (R) P.V. L.P.	
109								
110								
111								
112								
113	G.C. Bag Samp							
114								
115	E. B. (R)		E.B. (R)	E.B. (R)		E.B. (R)	E.B. (R)	
116								
117								
118	E.B. (R)		E.B. (R)	E.B. (R)		E.B. (R)	E.B. (R)	
119								
120	G.C. Bag Samp							
121	E.B. (H.F.)		E.B. (H.F.)	E.B. (H.F.)	E.B. (H.F.)	E.B. (H.F.)	E.B. (H.F.)	E.B. (H.F.)
122								
123	P.V. L.P.			P.V. L.P.		P.V. L.P.	P.V. L.P.	
124	E.B. (R)		E.B. (R)	E.B. (R)		E.B. (R)	E.B. (R)	
125								

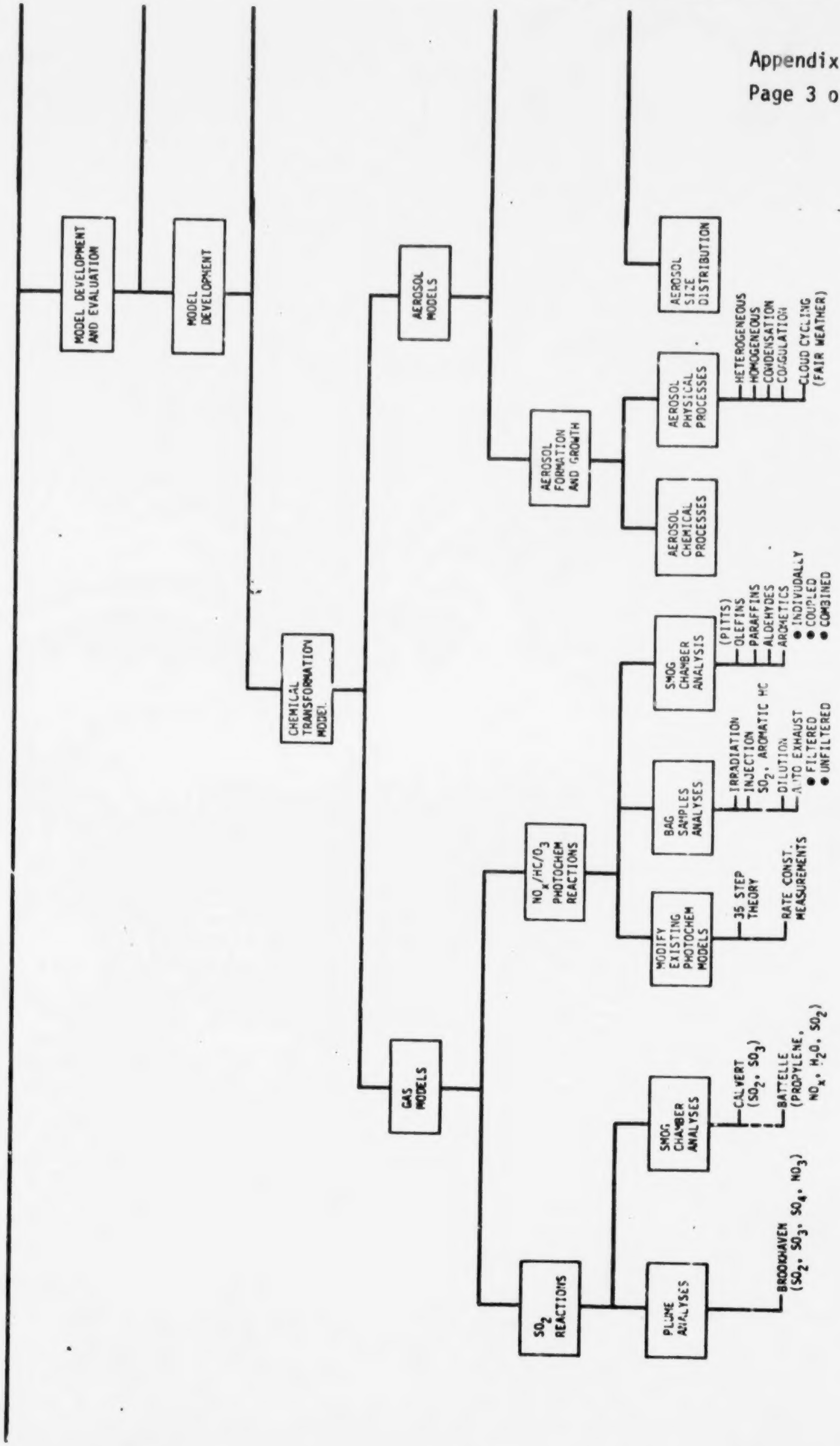
E.B. = Energy Budget
(R) = Radiation
L.P. = Long Path
(H.F.)= Heat Flux

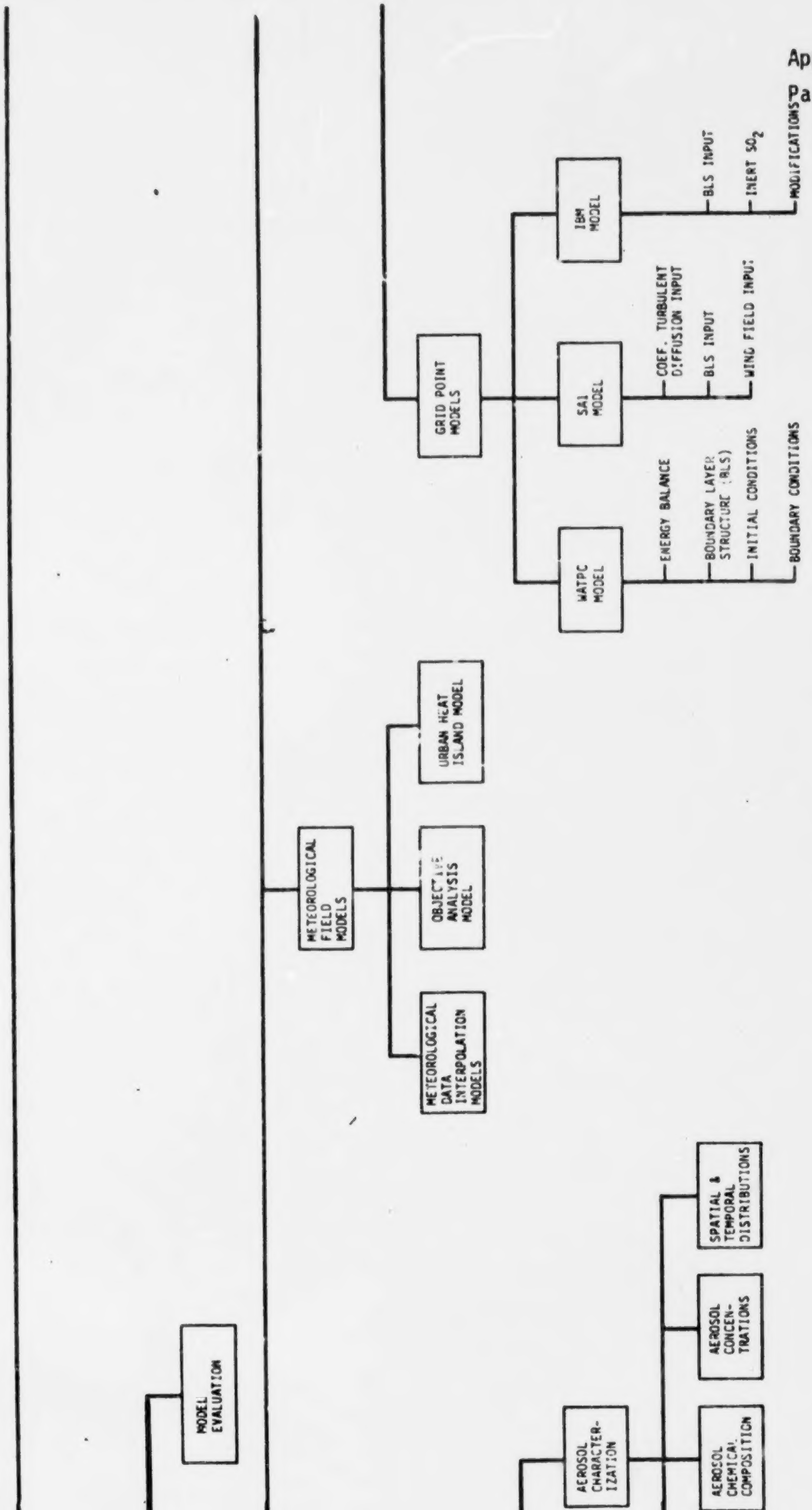
Figure 21. RAMS Station Field Expeditionary Utilization Matrix

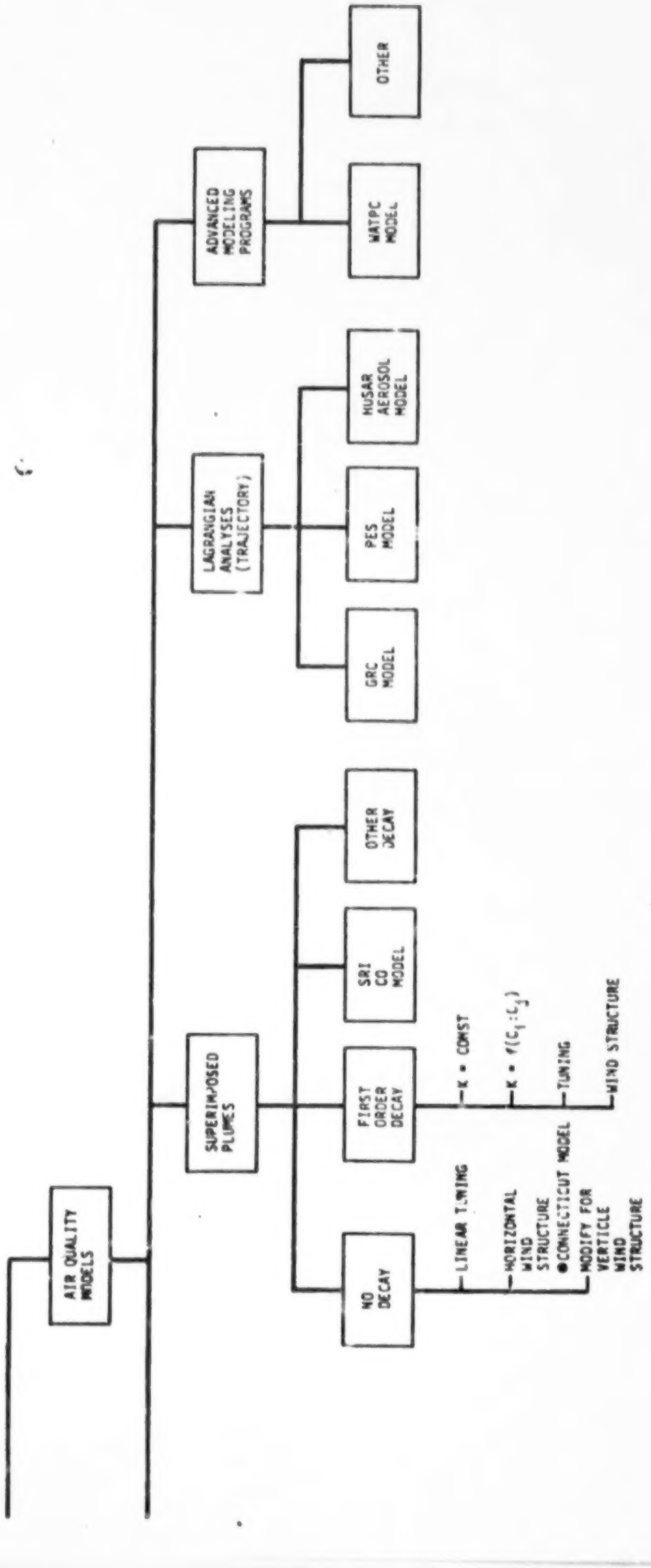

DATA MANAGEMENT
SYSTEM VALIDATION
RAPS DATA BANK
SYSTEM DESIGN
OBJECTIVES
PLAN
IMPLEMENTATION
TEST
QUALITY CONTROL PROGRAM
GUIDELINES
INDEPENDENT AUDIT
ROUTINE OPERATION
INSITU REVIEW
DATA INTEGRITY
STATUS + LIMIT CHECKS
CONSISTENCY AUDIT
FIELD EXPERIMENTS
RAMS
EMISSIONS
LOGISTICS
SUPPORTING DATA
NWS (LAMBERT FLD)
CAMP STATION
OTHER AGENCIES

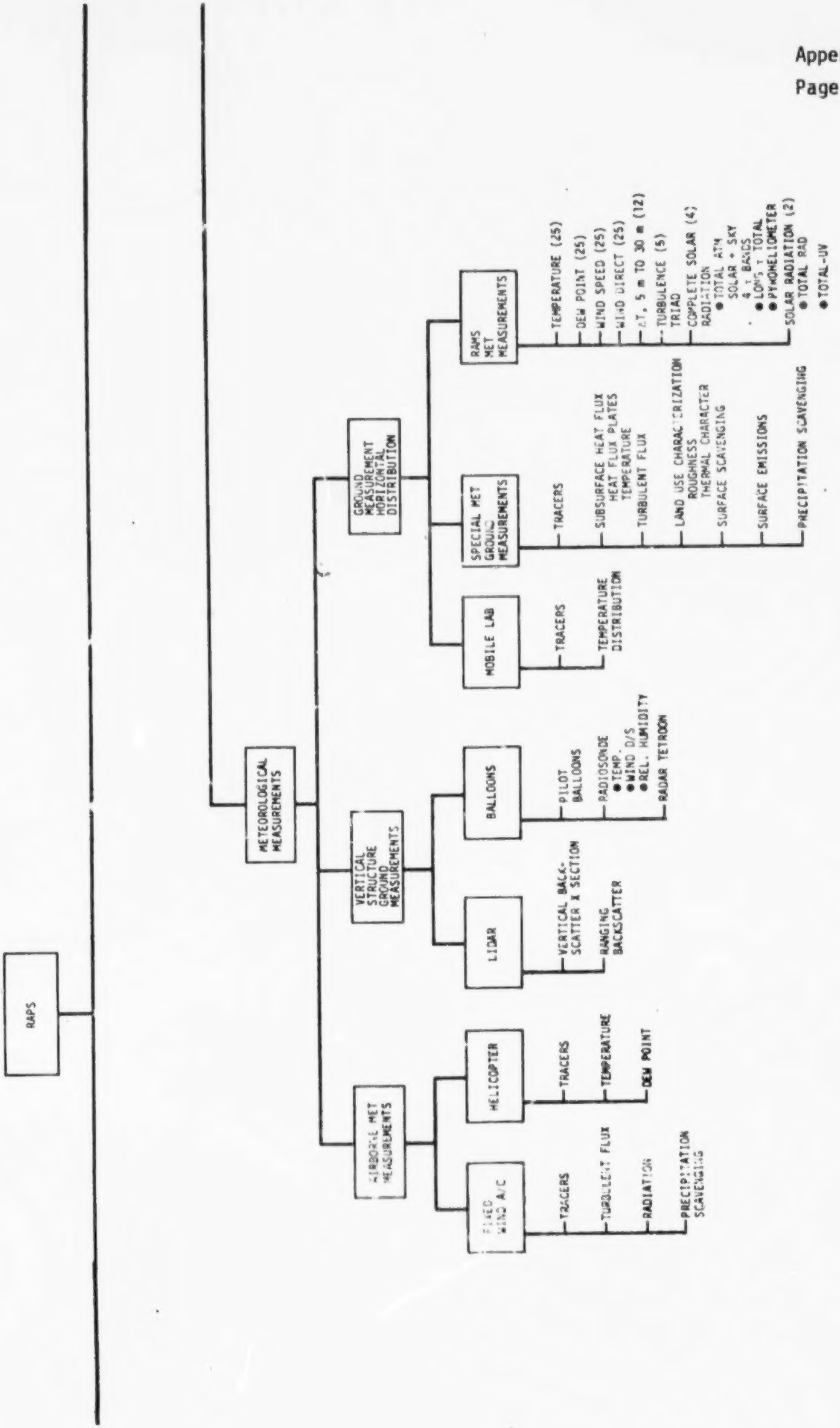
C. 73


SOFTWARE
COMPUTER FACILITIES
SYSTEM SOFTWARE
STD COMPILERS
DATA BASE L/NG
GRAPHICS SUPPORT
STATISTICAL ANALYSIS PROGRAM LIBRARY
UTILITY PROGRAMS
APPLICATIONS SOFTWARE
ANALYSIS
FORMAT GENERATION
STANDARDIZATION
DISPLAY
DATA BASE SOFTWARE
STRUCTURE
RETRIEVAL
REPORTS
UNIVAC 1110
GRAPHICS
TEKTRONIX (INTERACTIVE)
CALCOMP
REMOTE TERMINALS
BATCH
DEMAND
RAMS PDP 11/40 MINICOMPUTER
FORMAT CONVERSION PERIPHERALS
STL GRAPHICS (ELECTROSTATIC PLOTTER)
RTP MINICOMPUTER
MOVIE EQUIPMENT
REAL TIME DISPLAY


MODEL DEVELOPMENT AND EVALUATION
MODEL DEVELOPMENT
CHEMICAL TRANSFORMATION MODEL
AEROSOL MODELS
AEROSOL SIZE DISTRIBUTION
AEROSOL FORMATION AND GROWTH
AEROSOL PHYSICAL PROCESSES
HETEROGENEOUS
HOMOGENEOUS
CONDENSATION
COAGULATION
CLOUD CYCLING (FAIR WEATHER)
AEROSOL CHEMICAL PROCESSES
GAS MODELS
$NO_x/HC/O_3$ PHOTOCHEM REACTIONS
SMOG CHAMBER ANALYSIS
(PITTS)
OLEFINS
PARAFFINS
ALDEHYDES
AROMETICS
● INDIVUDUALLY
● COUPLED
● COMBINED
BAG SAMPLES ANALYSES
IRRADIATION
INJECTION
SO_2, AROMATIC HC
DILUTION
AUTO EXHAUST
● FILTERED
● UNFILTERED
MODIFY EXISTING PHOTOCHEM MODELS
35 STEP THEORY
RATE CONST. MEASUREMENTS
SO_2 REACTIONS
SMOG CHAMBER ANALYSES
CALVERT (SO_2, SO_3)
BATTELLE (PROPYLENE, NO_x, H_2O, SO_2)
PLUME ANALYSES
BROOKHAVEN (SO_2, SO_3, SO_4, NO_3)


MODEL EVALUATION
METEOROLOGICAL FIELD MODELS
METEOROLOGICAL DATA INTERPOLATION MODELS
OBJECTIVE ANALYSIS MODEL
URBAN HEAT ISLAND MODEL
GRID POINT MODELS
WATPC MODEL
ENERGY BALANCE
BOUNDARY LAYER STRUCTURE (BLS)
INITIAL CONDITIONS
BOUNDARY CONDITIONS
SAI MODEL
COEF. TURBULENT DIFFUSION INPUT
BLS INPUT
WIND FIELD INPUT
IBM MODEL
BLS INPUT
INERT SO2
MODIFICATIONS
AEROSOL CHARACTERIZATION
AEROSOL CHEMICAL COMPOSITION
AEROSOL CONCENTRATIONS
SPATIAL & TEMPORAL DISTRIBUTIONS


AIR QUALITY MODELS
SUPERIMPOSED PLUMES
LAGRANGIAN ANALYSES (TRAJECTORY)
ADVANCED MODELING PROGRAMS
NO DECAY
FIRST ORDER DECAY
SRI CO MODEL
OTHER DECAY
GRC MODEL
PES MODEL
HUSAR AEROSOL MODEL
WATPC MODEL
OTHER
LINEAR TUNING
HORIZONTAL WIND STRUCTURE
●CONNECTICUT MODEL
MODIFY FOR VERTICLE WIND STRUCTURE
K = CONST
K = f(C_i:C_j)
TUNING
WIND STRUCTURE


RAPS
METEOROLOGICAL MEASUREMENTS
AIRBORNE MET MEASUREMENTS
FIXED WING A/C
TRACERS
TURBULENT FLUX
RADIATION
PRECIPITATION SCAVENGING
HELICOPTER
TRACERS
TEMPERATURE
DEW POINT
VERTICAL STRUCTURE GROUND MEASUREMENTS
LIDAR
VERTICAL BACK-SCATTER X SECTION
RANGING BACKSCATTER
BALLOONS
PILOT BALLOONS
RADIOSONDE
● TEMP.
● WIND D/S
● REL. HUMIDITY
RADAR TETROON
GROUND MEASUREMENT HORIZONTAL DISTRIBUTION
MOBILE LAB
TRACERS
TEMPERATURE DISTRIBUTION
SPECIAL MET GROUND MEASUREMENTS
TRACERS
SUBSURFACE HEAT FLUX
HEAT FLUX PLATES
TEMPERATURE
TURBULENT FLUX
LAND USE CHARACTERIZATION
ROUGHNESS
THERMAL CHARACTER
SURFACE SCAVENGING
SURFACE EMISSIONS
PRECIPITATION SCAVENGING
RAMS MET MEASUREMENTS
TEMPERATURE (25)
DEW POINT (25)
WIND SPEED (25)
WIND DIRECT (25)
ΔT, 5 m TO 30 m (12)
TURBULENCE (5)
TRIAD
COMPLETE SOLAR (4)
RADIATION
● TOTAL ATM
SOLAR + SKY
4 λ BANDS
● LONG λ TOTAL
● PYRHELIOMETER
SOLAR RADIATION (2)
● TOTAL RAD
● TOTAL-UV

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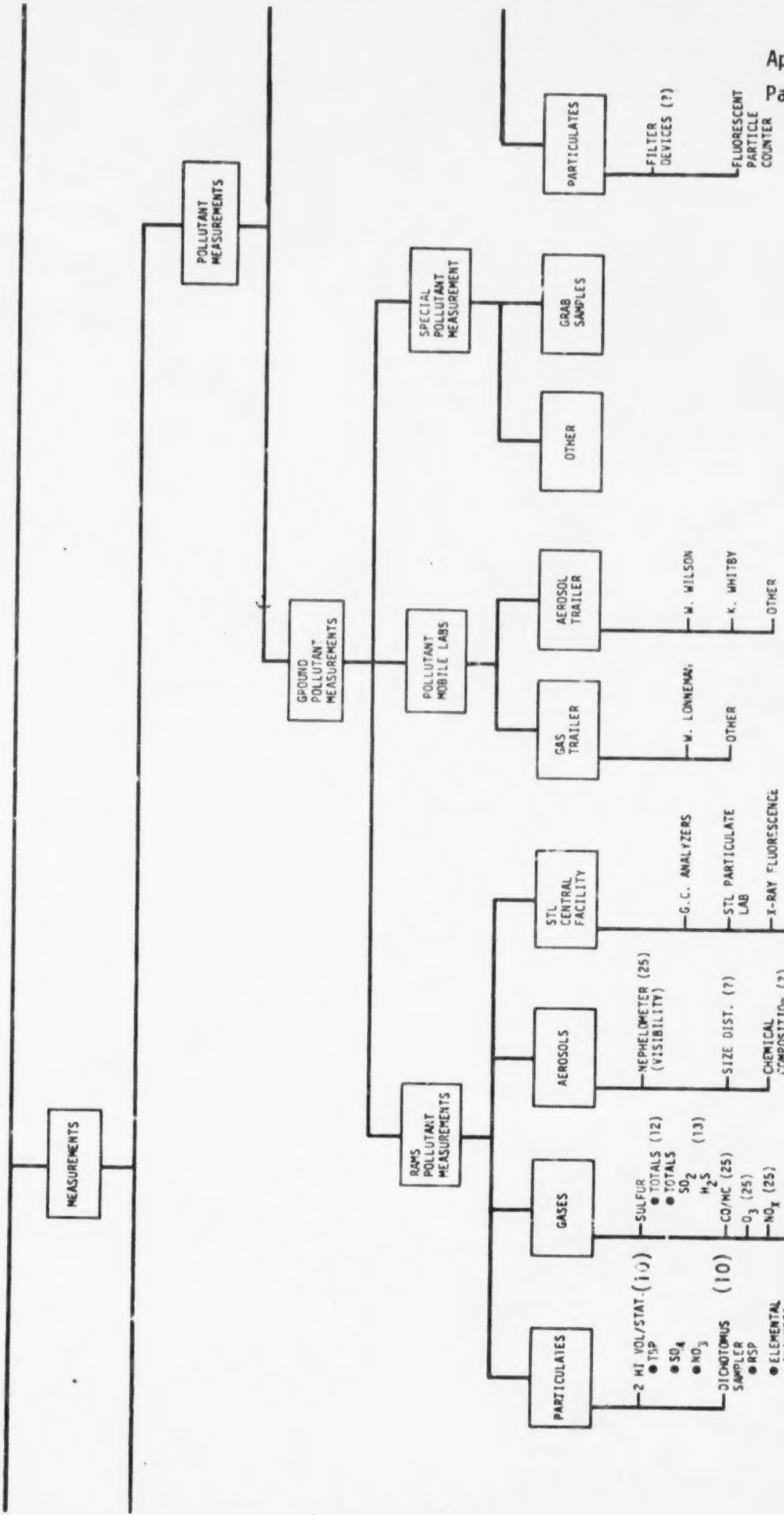
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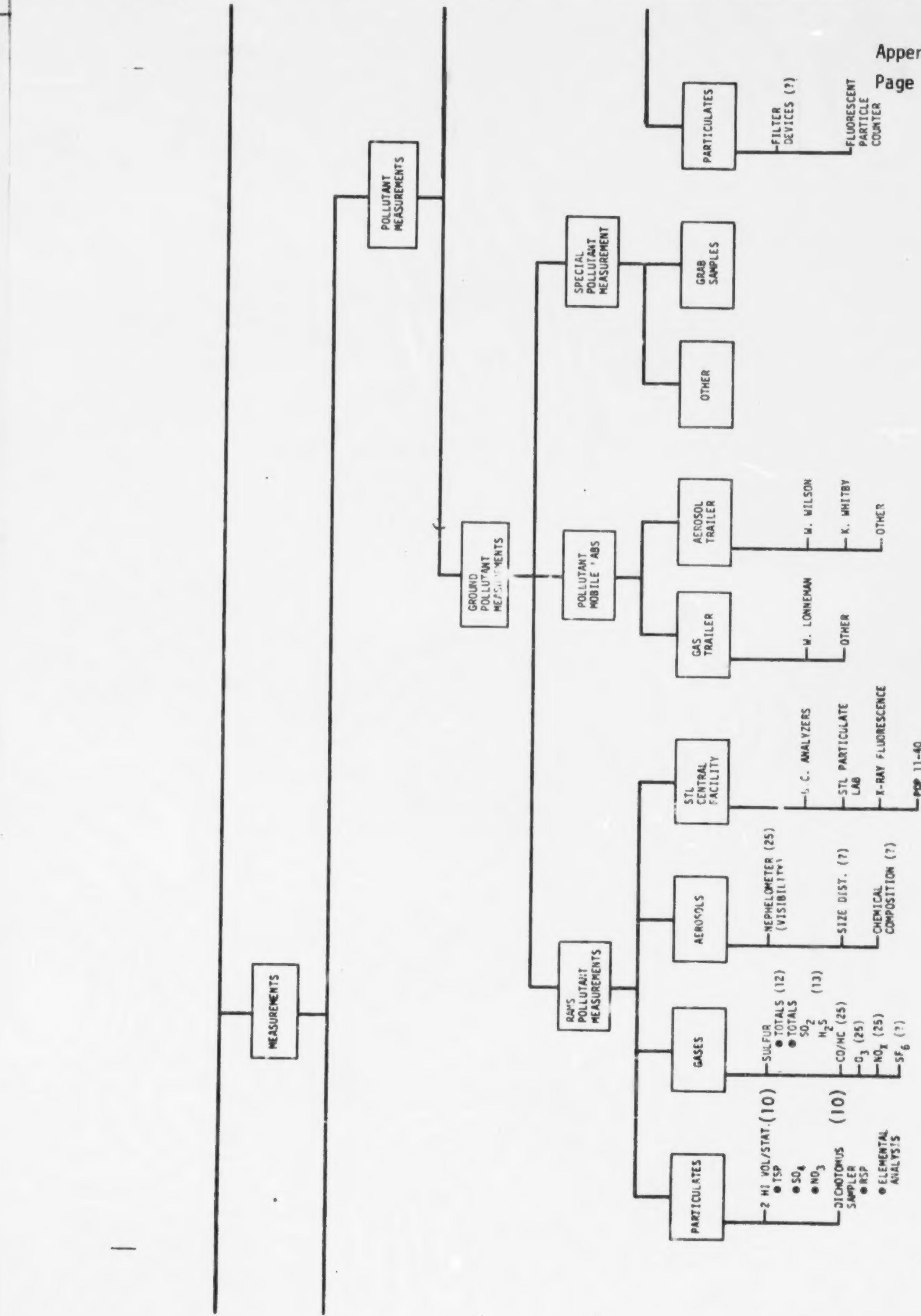
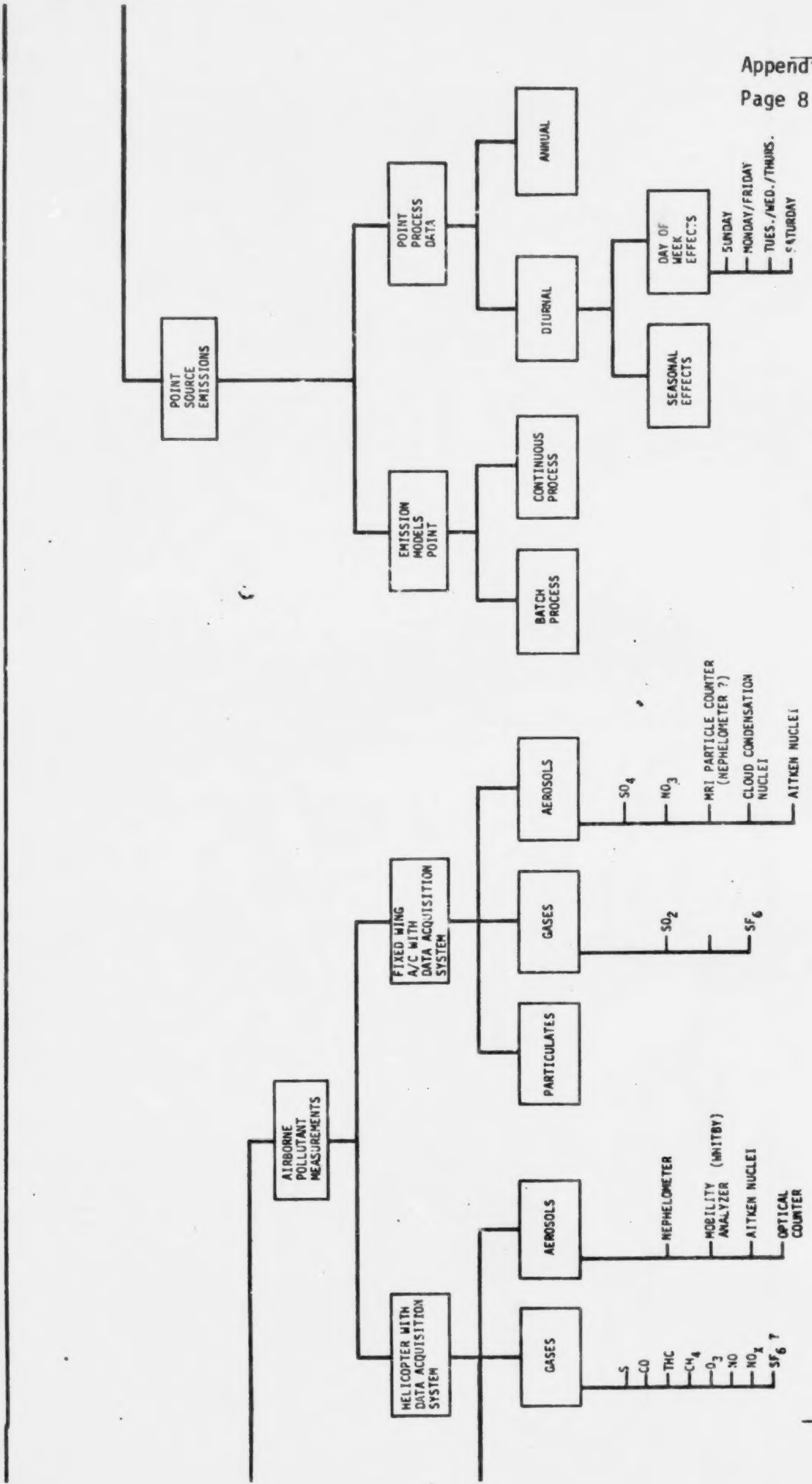
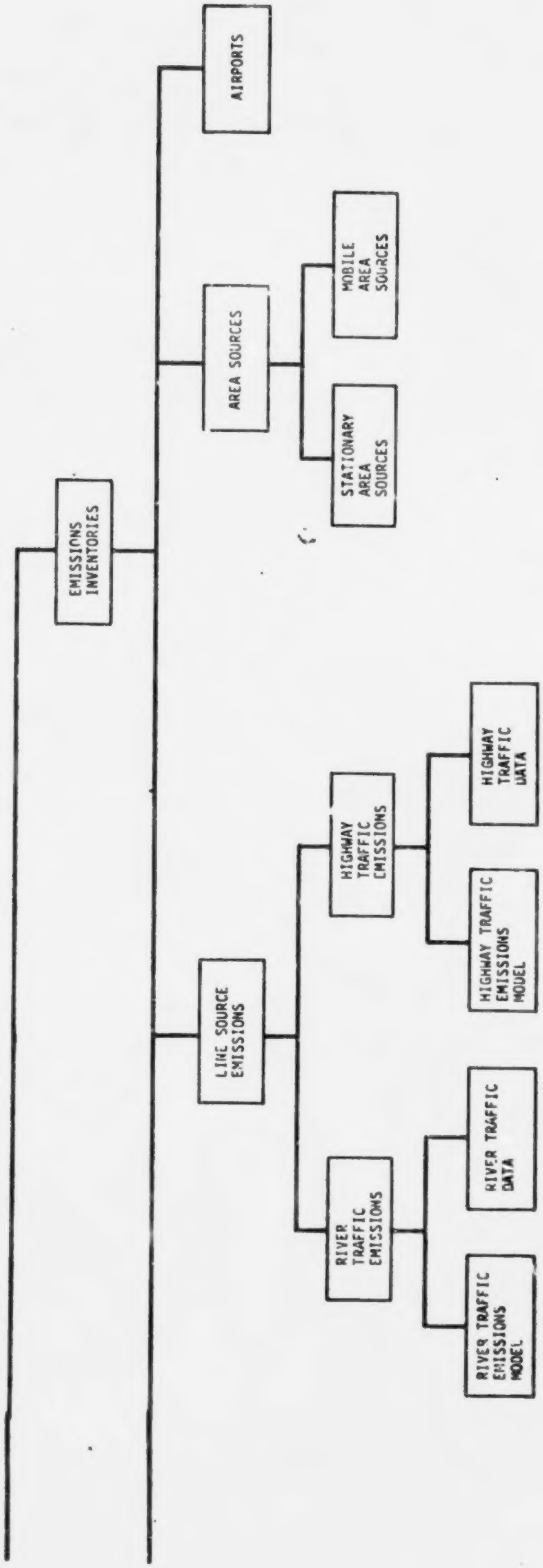
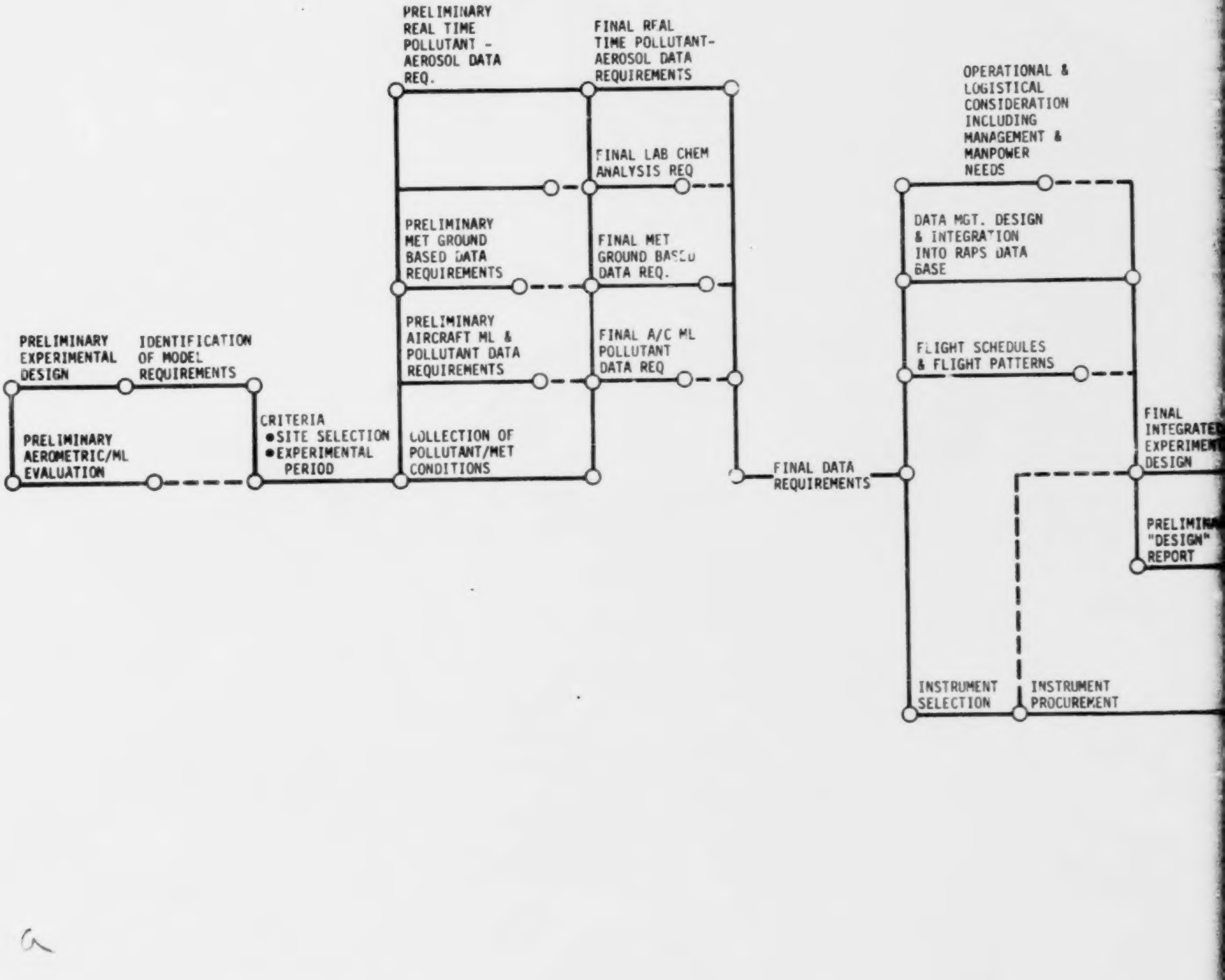
POLLUTANT MEASUREMENTS
GROUND POLLUTANT MEASUREMENTS
RAMS POLLUTANT MEASUREMENTS
PARTICULATES
2 HI VOL/STAT. (10)
● TSP
● SO_4
● NO_3
DICHOTOMUS SAMPLER (10)
● RSP
● ELEMENTAL ANALYSIS
GASES
SULFUR
● TOTALS (12)
● TOTALS SO_2 H_2S (13)
CO/HC (25)
O_3 (25)
NO_x (25)
SF_6 (?)
AEROSOLS
NEPHELOMETER (25) (VISIBILITY)
SIZE DIST. (?)
CHEMICAL COMPOSITION (?)
STL CENTRAL FACILITY
G.C. ANALYZERS
STL PARTICULATE LAB
X-RAY FLUORESCENCE
PDP 11-40
POLLUTANT MOBILE LABS
GAS TRAILER
W. LONNEMAN
OTHER
AEROSOL TRAILER
W. WILSON
K. WHITBY
OTHER
SPECIAL POLLUTANT MEASUREMENT
OTHER
GRAB SAMPLES
PARTICULATES
FILTER DEVICES (?)
FLUORESCENT PARTICLE COUNTER


MEASUREMENTS
POLLUTANT MEASUREMENTS
GROUND POLLUTANT MEASUREMENTS
RAMS POLLUTANT MEASUREMENTS
POLLUTANT MOBILE LABS
SPECIAL POLLUTANT MEASUREMENT
PARTICULATES
2 HI VOL/STAT. (10)
• TSP
• SO_4
• NO_3
DICHOTOMOUS SAMPLER (10)
• RSP
• ELEMENTAL ANALYSIS
GASES
SULFUR
• TOTALS (12)
• TOTALS (13)
SO_2
H_2S
CO/HC (25)
O_3 (25)
NO_x (25)
SF_6 (?)
AEROSOLS
NEPHELOMETER (25) (VISIBILITY)
SIZE DIST. (?)
CHEMICAL COMPOSITION (?)
STL CENTRAL FACILITY
G. C. ANALYZERS
STL PARTICULATE LAB
X-RAY FLUORESCENCE
PDP 11-40
GAS TRAILER
W. LONNEMAN
OTHER
AEROSOL TRAILER
W. WILSON
K. WHITBY
OTHER
OTHER
GRAB SAMPLES
PARTICULATES
FILTER DEVICES (?)
FLUORESCENT PARTICLE COUNTER

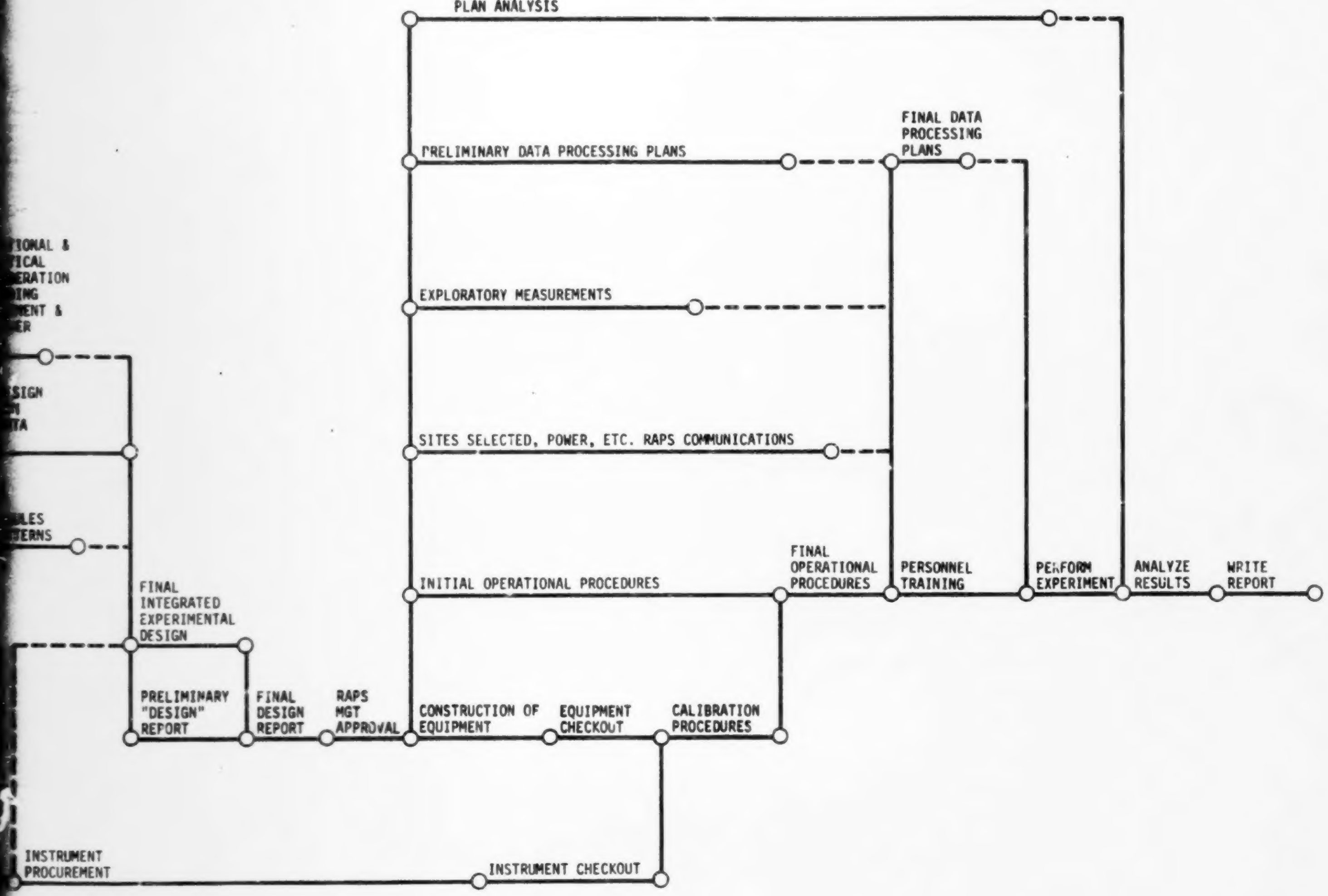

POINT SOURCE EMISSIONS
POINT PROCESS DATA
ANNUAL
DIURNAL
DAY OF WEEK EFFECTS
SUNDAY
MONDAY/FRIDAY
TUES./WED./THURS.
SATURDAY
SEASONAL EFFECTS
EMISSION MODELS POINT
CONTINUOUS PROCESS
BATCH PROCESS
AIRBORNE POLLUTANT MEASUREMENTS
FIXED WING A/C WITH DATA ACQUISITION SYSTEM
PARTICULATES
GASES
SO_2
SF_6
AEROSOLS
SO_4
NO_3
MRI PARTICLE COUNTER (NEPHELOMETER ?)
CLOUD CONDENSATION NUCLEI
AITKEN NUCLEI
HELICOPTER WITH DATA ACQUISITION SYSTEM
GASES
S
CO
THC
CH_4
O_3
NO
NO_x
SF_6 ?
AEROSOLS
NEPHELOMETER
MOBILITY ANALYZER (WHITBY)
AITKEN NUCLEI
OPTICAL COUNTER


EMISSIONS INVENTORIES
AIRPORTS
AREA SOURCES
MOBILE AREA SOURCES
STATIONARY AREA SOURCES
LINE SOURCE EMISSIONS
HIGHWAY TRAFFIC EMISSIONS
HIGHWAY TRAFFIC DATA
HIGHWAY TRAFFIC EMISSIONS MODEL
RIVER TRAFFIC EMISSIONS
RIVER TRAFFIC DATA
RIVER TRAFFIC EMISSIONS MODEL

PERT FOR FIELD EXPERIMENTAL TEST

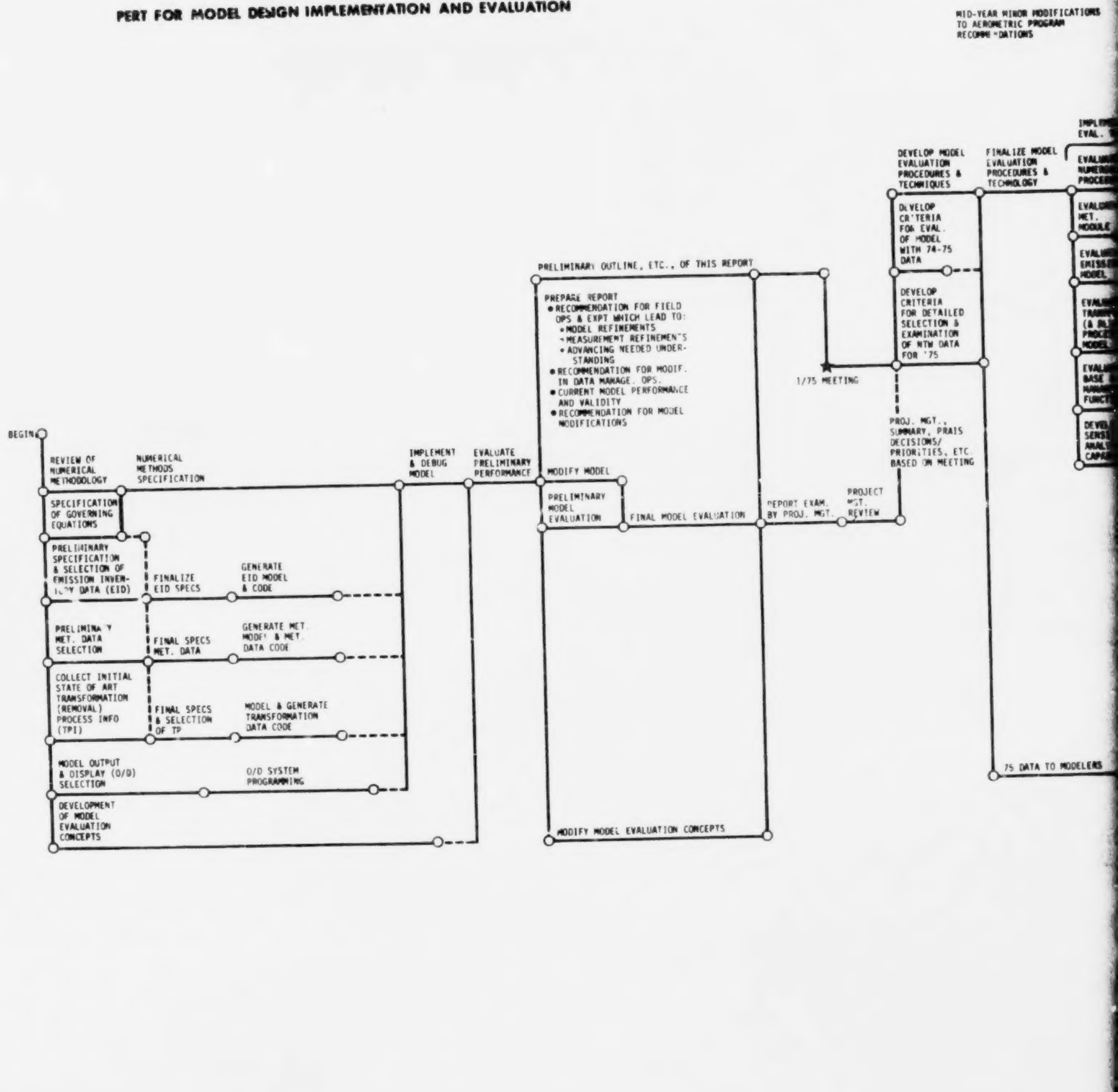

PRELIMINARY EXPERIMENTAL DESIGN
IDENTIFICATION OF MODEL REQUIREMENTS
PRELIMINARY AEROMETRIC/ML EVALUATION
CRITERIA
●SITE SELECTION
●EXPERIMENTAL PERIOD
PRELIMINARY REAL TIME POLLUTANT - AEROSOL DATA REQ.
PRELIMINARY MET GROUND BASED DATA REQUIREMENTS
PRELIMINARY AIRCRAFT ML & POLLUTANT DATA REQUIREMENTS
COLLECTION OF POLLUTANT/MET CONDITIONS
FINAL REAL TIME POLLUTANT-AEROSOL DATA REQUIREMENTS
FINAL LAB CHEM ANALYSIS REQ
FINAL MET GROUND BASED DATA REQ.
FINAL A/C ML POLLUTANT DATA REQ
FINAL DATA REQUIREMENTS
OPERATIONAL & LOGISTICAL CONSIDERATION INCLUDING MANAGEMENT & MANPOWER NEEDS
DATA MGT. DESIGN & INTEGRATION INTO RAPS DATA BASE
FLIGHT SCHEDULES & FLIGHT PATTERNS
FINAL INTEGRATE EXPERIMEN DESIGN
PRELIMINA "DESIGN" REPORT
INSTRUMENT SELECTION
INSTRUMENT PROCUREMENT

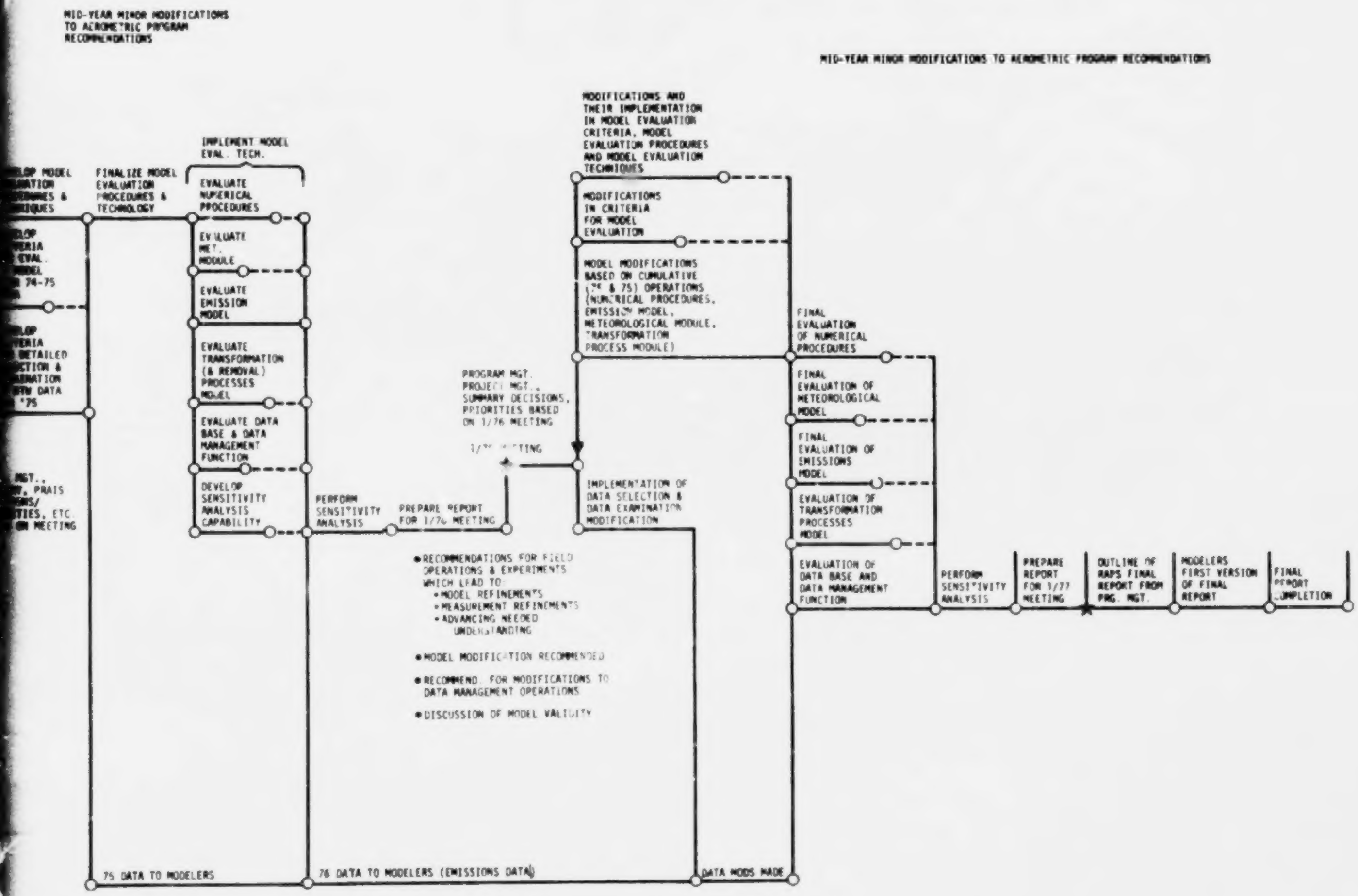
a


PLAN ANALYSIS
PRELIMINARY DATA PROCESSING PLANS
FINAL DATA PROCESSING PLANS
EXPLORATORY MEASUREMENTS
SITES SELECTED, POWER, ETC. RAPS COMMUNICATIONS
INITIAL OPERATIONAL PROCEDURES
FINAL OPERATIONAL PROCEDURES
PERSONNEL TRAINING
PERFORM EXPERIMENT
ANALYZE RESULTS
WRITE REPORT
TIONAL & TICAL ERATION DING MENT & ER
SIGN H TA
ULES TERNS
FINAL INTEGRATED EXPERIMENTAL DESIGN
PRELIMINARY "DESIGN" REPORT
FINAL DESIGN REPORT
RAPS MGT APPROVAL
CONSTRUCTION OF EQUIPMENT
EQUIPMENT CHECKOUT
CALIBRATION PROCEDURES
INSTRUMENT PROCUREMENT
INSTRUMENT CHECKOUT

b

PERT FOR MODEL DESIGN IMPLEMENTATION AND EVALUATION


MID-YEAR MINOR MODIFICATIONS TO AEROMETRIC PROGRAM RECOMM-DATIONS
BEGIN
REVIEW OF NUMERICAL METHODOLOGY
NUMERICAL METHODS SPECIFICATION
SPECIFICATION OF GOVERNING EQUATIONS
PRELIMINARY SPECIFICATION & SELECTION OF EMISSION INVEN-TORY DATA (EID)
FINALIZE EID SPECS
GENERATE EID MODEL & CODE
PRELIMINARY MET. DATA SELECTION
FINAL SPECS MET. DATA
GENERATE MET. MODEL & MET. DATA CODE
COLLECT INITIAL STATE OF ART TRANSFORMATION (REMOVAL) PROCESS INFO (TPI)
FINAL SPECS & SELECTION OF TP
MODEL & GENERATE TRANSFORMATION DATA CODE
MODEL OUTPUT & DISPLAY (O/D) SELECTION
O/D SYSTEM PROGRAMMING
DEVELOPMENT OF MODEL EVALUATION CONCEPTS
IMPLEMENT & DEBUG MODEL
EVALUATE PRELIMINARY PERFORMANCE
MODIFY MODEL
PRELIMINARY MODEL EVALUATION
FINAL MODEL EVALUATION
MODIFY MODEL EVALUATION CONCEPTS
PRELIMINARY OUTLINE, ETC., OF THIS REPORT
PREPARE REPORT
• RECOMMENDATION FOR FIELD OPS & EXPT WHICH LEAD TO:
• MODEL REFINEMENTS
• MEASUREMENT REFINEMENTS
• ADVANCING NEEDED UNDER-STANDING
• RECOMMENDATION FOR MODIF. IN DATA MANAGE. OPS.
• CURRENT MODEL PERFORMANCE AND VALIDITY
• RECOMMENDATION FOR MODEL MODIFICATIONS
REPORT EXAM. BY PROJ. MGT.
PROJECT MGT. REVIEW
1/75 MEETING
PROJ. MGT., SUMMARY, PRAIS DECISIONS/ PRIORITIES, ETC. BASED ON MEETING
DEVELOP MODEL EVALUATION PROCEDURES & TECHNIQUES
DEVELOP CRITERIA FOR EVAL. OF MODEL WITH 74-75 DATA
DEVELOP CRITERIA FOR DETAILED SELECTION & EXAMINATION OF NTW DATA FOR '75
FINALIZE MODEL EVALUATION PROCEDURES & TECHNOLOGY
75 DATA TO MODELERS
IMPL
EVAL.
EVAL
NUME
PROCE
EVAL
MET.
MODULE
EVAL
EMISS
MODEL
EVAL
TRAN
(& AL
PROCE
MODEL
EVAL
BASE
MANA
FUNCT
DEVEL
SENSI
ANAL
CAPA


MID-YEAR MINOR MODIFICATIONS TO AEROMETRIC PROGRAM RECOMMENDATIONS
MID-YEAR MINOR MODIFICATIONS TO AEROMETRIC PROGRAM RECOMMENDATIONS
LOP MODEL UATION EDURES & NIQUES
LOP ERIA EVAL. MODEL 74-75
LOP ERIA DETAILED CTION & INATION DATA '75
MGT., PRAIS NS/ TIES, ETC ON MEETING
FINALIZE MODEL EVALUATION PROCEDURES & TECHNOLOGY
IMPLEMENT MODEL EVAL. TECH.
EVALUATE NUMERICAL PROCEDURES
EVALUATE MET. MODULE
EVALUATE EMISSION MODEL
EVALUATE TRANSFORMATION (& REMOVAL) PROCESSES MODEL
EVALUATE DATA BASE & DATA MANAGEMENT FUNCTION
DEVELOP SENSITIVITY ANALYSIS CAPABILITY
PERFORM SENSITIVITY ANALYSIS
PREPARE REPORT FOR 1/76 MEETING
PROGRAM MGT. PROJECT MGT., SUMMARY DECISIONS, PRIORITIES BASED ON 1/76 MEETING
1/76 MEETING
MODIFICATIONS AND THEIR IMPLEMENTATION IN MODEL EVALUATION CRITERIA, MODEL EVALUATION PROCEDURES AND MODEL EVALUATION TECHNIQUES
MODIFICATIONS IN CRITERIA FOR MODEL EVALUATION
MODEL MODIFICATIONS BASED ON CUMULATIVE (75 & 75) OPERATIONS (NUMERICAL PROCEDURES, EMISSION MODEL, METEOROLOGICAL MODULE, TRANSFORMATION PROCESS MODULE)
IMPLEMENTATION OF DATA SELECTION & DATA EXAMINATION MODIFICATION
• RECOMMENDATIONS FOR FIELD OPERATIONS & EXPERIMENTS WHICH LEAD TO:
• MODEL REFINEMENTS
• MEASUREMENT REFINEMENTS
• ADVANCING NEEDED UNDERSTANDING
• MODEL MODIFICATION RECOMMENDED
• RECOMMEND. FOR MODIFICATIONS TO DATA MANAGEMENT OPERATIONS
• DISCUSSION OF MODEL VALIDITY
FINAL EVALUATION OF NUMERICAL PROCEDURES
FINAL EVALUATION OF METEOROLOGICAL MODEL
FINAL EVALUATION OF EMISSIONS MODEL
EVALUATION OF TRANSFORMATION PROCESSES MODEL
EVALUATION OF DATA BASE AND DATA MANAGEMENT FUNCTION
PERFORM SENSITIVITY ANALYSIS
PREPARE REPORT FOR 1/77 MEETING
OUTLINE OF RAPS FINAL REPORT FROM PRG. MGT.
MODELERS FIRST VERSION OF FINAL REPORT
FINAL REPORT COMPLETION
75 DATA TO MODELERS
76 DATA TO MODELERS (EMISSIONS DATA)
DATA MODS MADE

BUDGET SUMMARY

The RAPS Emission Inventory

This section of the handbook deals with background information relating to the RAPS emission inventory. The purpose of the emission inventory is discussed in relation to the overall program in Section 1. A list of the RAPS participants is presented in Section 2 along with a description of the portion of the emission inventory for which they are responsible. The third section deals with the user and the uses they plan to put the emission inventory to. The fourth section is somewhat different. It addresses the problem of how to obtain additional emission inventory information which is not gathered by the National Air Data Branch for the RAPS program. The last section presents St. Louis NEDS emission data in an illustrative manner (Section 5). The reader is given background information on NEDS and how it can be applied using St. Louis as an example.

1. RAPS Preliminary Emission Inventory, Stanford Research Institute, PB 232-223, January 1974

2. RAPS Participants, prepared by National Air Data Branch for this Handbook, April 1975

3. See 1.

4. Special Emission Inventories for Field Studies, Rockwell International, Science Center, Contract No.68-02-1081, 1974

5. Presentation of NEDS Emission Data for Air Pollution Studies Research Triangle Institute, Contract No. 68-02-1096, Task 5

RAPS PRELIMINARY EMISSION INVENTORY

1. Purpose of Inventory

The requirements of the RAPS program are wide ranging, diverse, and, in many cases, stipulate degrees of spatial and temporal resolution that have not hitherto been achieved. For the multiple purposes of the RAPS program, it is thus more appropriate to consider data on pollutant emissions in terms of a system of data resources than in terms of a single all-serving emission inventory. Alternatively, one can look upon an emission inventory for RAPS as being a multifaceted data source that comprises a number of elements, which are capable of providing needed information as required. In either case, we are led to a system in which varying criteria are applied to determining the nature and extent of the inventory content.

A major distinction can be drawn between the requirements of RAPS for high resolution data (in space and time), for such purposes as the verification and development of air quality models, and the more general needs of the program, such as, for example, investigations of economic, social, or political processes, or the investigation of control or abatement strategies not immediately served by the air quality modeling studies. This distinction leads immediately to a concept in which a special high resolution inventory (for pollutants of significance) is provided to the air quality modeling studies and other investigations (such as transportation processes or improved inventory methodology) where such high resolution data is appropriate. Those pollutants are SO_2, NO_x, CO, and hydrocarbons (HCs). For other pollutants, the high costs and difficulties of providing such high resolution emission data on a routine basis are not justified. For such other pollutants, we recommend that the National Emissions Data System (NEDS) Inventory be used.

When special information on emissions is required--for example, for extra precise high resolution data for limited "maximum effort" periods of model validation or for intensive transformation process investigations--we recommend that each such emission data collected be treated as a special case. This will avoid placing excessive requirements on the basic emission inventories and save cost and effort.

It is convenient, therefore, in speaking of the RAPS emission inventory, to consider it primarily as the specially developed, high resolution data source concerned initially with SO_x, NO_x, CO, and HC. This inventory, as noted, must be flexible and capable of serving many purposes.

To ensure this, it is necessary to retain the basic or prime data from which it is built in its compilations in order to make revisions or extensions readily possible. Data should not be lumped in a form that applies to a single, or narrowly perceived, requirement.

The most satisfactory approach, wherever possible, is to provide files of emissions data for each pollutant in terms of direct statements of weight of pollutant emitted by each source or class of sources as a function of point or area location for every hour. Although this is a substantial undertaking, as described below, in most cases it can be accomplished to a useful level of precision within the RAPS program. This is mainly because the bulk of the emissions is a result of a limited number of sources. In a program of the scope of RAPS, it is possible to treat such sources individually and to use measured data providing direct or closely related information on emissions as the basis for hourly emission estimates. The frequency and quality of the measurements will be proportional to the magnitude of each source. This approach differs from that commonly used in developing emission data for purposes similar to the RAPS main objectives, which has perforce relied heavily upon emission modeling techniques to interpolate from gross annual data to provide information with high nominal temporal resolution. In the proposed RAPS inventory, such modeling techniques would only be applied to estimating hourly emissions from minor point sources or from area sources, although in certain of these cases it is recommended that the required precision demands the development of improved modeling methods for providing hourly data. In the case of mobile sources, however, where considerable progress has been made in assessing emissions with high spatial and temporal resolution, the current modeling approach is suitable for the RAPS inventory; the records of mobile sources to be incorporated in the inventory have a special form.

The term "emission modeling" sometimes leads to confusion, and it is necessary to clarify its significance. Strictly speaking, any computational manipulation of raw data can be described as modeling, for example, the combination of pollutant concentrations and flow rates to provide emission estimates. More often, modeling applies to the derivation or estimations of emissions from limited prime data, such as the estimation of emissions from residential space heating on an area basis (from a consideration of population density and daily temperature). In particular, the apportionment of emissions from any source or class of sources on, say, an hourly basis, from data such as gross annual tonnage of fuel burnt, is commonly performed by modeling using expressions (which can be more or less arbitrary) to describe the patterns of variability that occur by season, by day of the week, or by hour of the day.

In a more comprehensive sense, various emission models have been developed for specific purposes. These may consist of series of sub-elements integrated into a single system for deriving required emissions data. Such models are generally intended to provide emissions data in a specified form suitable for a particular use, deriving their estimates from relatively limited prime data (usually that relating to gross annual fuel consumption). A typical example is the Argonne Hourly SO_2 Model.[1] This model, described in detail in Section 6 , provides hourly estimates of SO_2 and thermal emissions from power plants, industrial point sources, and one-square-mile areas of residential, commercial, and institutional sources. It derives such estimates from a range of input parameters based largely upon fuel consumption statistics as well as upon other factors such as temperature and time.

In considering such comprehensive emission models, it is important to emphasize their limitations for the purposes of RAPS. Adequate though they may be for the uses for which they were developed, they reflect the expediency and economy that was appropriate to such use. They seek to provide the best emissions estimates possible from available (i.e., minimal) data. They are not the best approach to developing emission inventories if better data can be specially acquired--as it can in the case of RAPS. Another aspect of emission models is the way that the specific output requirements determine the manner of developing the emission estimates from the prime data. This generally results in a lack of the flexibility needed to meet the multiple and varied demands of RAPS. The RAPS Emission Inventory should make emissions information available in such a manner that any desired selection of data may be extracted and presented in any desired form. This requirement is met by providing emission data in the form noted above, i.e., as direct statements of weight of pollutant emitted by each source, or class of sources as a function of location for every hour. In this approach, the emission modeling techniques, where used, are limited to the production of a common database, i.e., the general purpose high resolution emission inventory. The task of extracting emissions data for any purpose and of presenting it in any appropriate form then becomes a separate function.

It is recommended, therefore, that the RAPS inventory be developed upon the basis of specially collected data, rather than upon current emission models (with the exception of mobile source data). Further, it is recommended that the inventory provides flexibility and universality by being a simple compilation of all required data in the lowest common denominator form, i.e., hourly emissions by weight of each pollutant (SO_2, NO_x, HC, and CO).

For other pollutants, it is recommended that the National Emissions Data System (NEDS) be used.

2. RAPS Participants

Since the National Air Data Branch, Monitoring and Analysis Division, Office of Air Quality Planning and Standards, Office of Air and Waste Management, is the organization within the Environmental Protection Agency charged with maintenance of emission inventories as well as emission factors, NADB was assigned lead responsibility for the emission inventory in the St. Louis AQCR.

The National Air Data Branch maintains the NEDS (National Emission Data Systems) inventory, which provides uniform, nationwide computerized coverage of emission data, obtained orginally by local air pollution control agencies. In the St. Louis area, this comprises the following agencies:

Missouri Air Conservation Commission

Air Pollution Control Div., St. Louis County Health Dept.

Air Pollution Control, City of St. Louis

Illinois Environmental Protection Agency

This inventory is based on annual figures; since the requirements of RAPS dictated a more detailed resolution, NADB contracted with a number of companies to provide the necessary inputs. The following is an alphabetized list of the contractors and their principal contributions:

Environmental Science and Engineering	- Area Sources Methodology
GCA/Technology	- Hydrocarbon Emissions Methodology - Airport Emission Methodology
Rockwell International Science Center Air Monitoring Center	- Point Source Methodology - Special Inventories for Field Studies - Emission Inventory Data Handling System - Heat Emissions - Non-Criteria Pollutant Inventory - Particle Size Distribution Inventory
Stanford Research Institute	- RAPS Preliminary Emission Inventory
Washington University	- Automotive Line and Area Source Methodology

In addition the Department of Transportation has contributed resources and manpower into helping the National Air Data Branch develop the RAPS Emission Inventory.

Department of Transportation Transportation Systems Center	- River Vessel Methodology and Inventory - Rail Methodology and Inventory
Federal Highway Administration	- Automotive Line and Area Source Inventory

The National Air Data Branch is using several analyses developed for use on the National Emission Data System. These analyses will be applied to the RAPS emission inventory. They are:

IBM-Federal Systems Division	- Weighted Sensitivity Analysis
PEDCo-Environmental	- Source Inventory Percision Analysis
Research Triangle Institute	- Computer Assisted Area Source Emission Gridding Procedure - Presentation of NEDS Emission Data

3. DEFINITION OF POTENTIAL USERS AND USES

A. General

An emission inventory is a fundamental part of any air pollution study. The Regional Air Pollution Study (RAPS) in Saint Louis is expected to be unique in scope and depth. Consequently, the emission inventory contemplated for this study needs to be far more detailed and accurate than those currently available.

The actual scope, content, and format of the RAPS inventory is determined by its proposed use, and, in order to ensure that the inventory will correspond as closely as possible to the demands placed on it by future users, a survey was made to determine the characteristics desired by potential users both within EPA and elsewhere. Primary consideration was given to RAPS requirements. To complete the picture, the needs of other potential users were then considered.

B. Summary

Although an emission inventory is a key information base for all air pollution studies and control strategies, it is of direct use to RAPS investigators concerned with the relationship between ambient concentrations of pollutants and their source, that is, the modelers. Other groups directly concerned with emission inventories are (1) the regulatory agencies charged with the achievement and maintenance of the National Air Standards (this group has the responsibility and authority to collect and store emission data) and (2) other workers in the field concerned with transportation problems, health effects, plant damage, and the like (these groups are primarily concerned with ambient concentrations of pollutants of interest).

The requirements of these users are quite different. The modelers are concerned primarily with those pollutants for which air quality standards have been promulgated, that is, sulfur dioxide, carbon monoxide, hydrocarbons, nitrogen dioxide, and suspended particulates. The information they require is very detailed (accurate location of the sources, detailed information on emissions as a function of time, and precise estimates of quantities emitted are all essential). The period for which such high resolution data is needed will vary considerably. In many cases, model verifications will be limited to relatively short periods, of, say, 48 to 72 hours, selected for representative meteorological conditions. Since such periods may not be readily determinable until a later time, when the best combination of circumstances is determined, post facto, it is necessary to collect appropriate emissions data on a continuing basis, parallel with the even more comprehensive continuous measurements of air quality and meteorological factors.

The requirements of the people working with health effects or plant damage, on the other hand, are quite different. The range of pollutants of interest is very broad, including not only compounds of known toxic effects such as mercury or cadmium but also an almost infinite variety of compounds suspected of having an effect on plants or people. For these purposes, detailed time resolution of emission is seldom required (except in cases of accidents or unusual meteorological events) since most effects are cumulative over long periods of time. Therefore, long-time historical records on many substances are of main importance in determining causative relationships of air pollution to health or vegetation effects.

State and local regulatory agencies are in a sense caught between these two requirements. They have to maintain inventories adequate for the enforcement of legal standards, and they would like to have records of emissions that are potentially hazardous.

As RAPS may eventually include a number of investigations that currently are not well defined, it is essential to include in the inventory design the flexibility required for the addition of other pollutants. For the moment, however, the primary users of the RAPS emission inventory are the modelers, and it is their requirements that have to be met. In the following section the details of these requirements are delineated. Table 1 summarizes the requirements.

C. RAPS Requirements

The Saint Louis emission inventory is of prime concern to the RAPS research groups engaged in the development, evaluation, and refinement of air pollution models. Several types of models are currently under consideration or active study as part of one RAPS study plan;[7] in this plan, the four basic model types are emission, atmospheric structure, transformation, and removal process models. Also being considered are existing models that encompass one or more of the basic models, such as some models that treat the generation and dispersion of pollutants from certain transportation sources.

Table 1

EMISSION INVENTORY REQUIREMENTS

Requirements / Uses or Users	Type of Source			Spatial Resolution														Average Time Resolution					
				Point		Area				Line									
										Endpoints									
	Point	Area	Line	0.1 km	0.01 km	<1 km^2	1 km^2	>1 km^2	Other	UTM	Intersections	Width (meters)	Centerstrip Width (meters)	Type	Year	Season	Month	Week	Day	Hour
RAPS Models																				
Atmospheric structure	x	x			x		x													x
Transformation processes	x	x	x		x		x			x										x
Vehicular sources			x							x		x	x	x						x
Airport model	x		x	Each plane							Runway-taxiway-gate						Each flight			
Regulatory Agency																				
City of Saint Louis APC	x	x	x	x		x					x				x	x				
Saint Louis County APC	x	x	x	x		x					x				x	x				
Illinois State APC	x	x	x	x		x									x	x			x	
Missouri Air Control Commission	x	x	x	x		x									x	x			x	
Research																				
Metromex	x			x																x
CHESS									School districts						x					x
Plant damage studies	x			x													x	x		

Requirements / Uses or Users	Units		Pollutants																			
	Metric	Engineering	SO$_2$	CO	NO$_x$	Oxidant	O$_3$	PAN	Hydrocarbons	Hydrocarbons by Groups	Hydrocarbons by Compounds	Particulates	Water Vapor	Heat	Fluorides	Sulfates	Asbestos	Trace Metals	BaP	PCB	Pollen	Hazardous Materials
RAPS Models																						
Atmospheric structure	x		x	x								x	x	x								
Transformation processes	x		x	x	x	x					x	x										
Vehicular sources	x			x	x					x		x										
Airport model	x			x	x				x			x										
Regulatory Agency																						
City of Saint Louis APC		x	x	(x)	x				(x)			x										
Saint Louis County APC		x	x	x	x				x			x										
Illinois State APC		x	x	x	x				x			x										
Missouri Air Control Commission		x	x	x	x				x			x										
Research																						
Metromex	x											x										
CHESS	x		x	x	x	x	x				x	x				x	x	x	x	x	x	x
Plant damage studies	x		x		x		x	x							x							

Upon examination of the four basic models, it can be seen that only the emission model is self-contained. The others exhibit various degrees of interdependence. For example, a model of boundary layer structure will need to account for the meteorological effects that result from emissions of, say, heat and water vapor. Similarly, transformation models must consider both emissions and atmospheric structure models, while removal process models consider all three models. Thus, in assessing the requirements of the various specific models, we need to recognize that, while the primary emphasis of the particular model may be one thing, it is quite likely and indeed probable that many of its input requirements derive from the structure of the other model components.

Up to now little effort has been devoted to the development of comprehensive or nonspecialized emission models. In fact, the development of a framework for a RAPS emission model program is an objective of this study. In the absence of an established emission model that the emission inventory would serve, we have surveyed the various model requirements for emission inputs so as to specify criteria and objectives for such an inventory. These models and their requirements are discussed below.

1. Atmospheric Structure Models

Atmospheric structure models describing transport and diffusion within the planetary layer on a regional scale (≤30 km) are being developed at the Model Development Branch, Meteorology Laboratory, NERC, Research Triangle Park, North Carolina. The specific requirements related to emissions are shown in Table 2. The model is currently under development, and, hence, these requirements reflect our best judgment based on available information. Three additional models used at the Meteorology Laboratory of NERC are

- PTMAX, an interactive program that performs an analysis of the maximum, short-term concentration from a point source as a function of stability and wind speed.
- PTDIS, an interactive program that computes short-term concentrations downwind from a point source at distances specified by the user.
- PTMTP, an interactive program that computes, at multiple receptors, short-term concentrations resulting from multiple point sources.

Table 2

EMISSION INVENTORY INPUT REQUIREMENTS
FOR ATMOSPHERIC STRUCTURE (WATPIC) MODEL

Content of inventory	SO_2, CO, particulates, heat, water vapor
Time resolution	1 hour
Spatial resolution	Point sources on UTM grid (±0.01 km) Area sources on variable grid from 1 km^2
Preferred medium	Tape
Units	Grams/second, watts
Source descriptors	Stack height (meters), exit velocity (meters/second), temperature (°K), stack diameter (meters)
Temporal variations	Diurnal, daily, seasonal
Level of confidence	Depends on source of data (stack sampling, questionnaires)

We believe that the emission inventory input requirements of these models are met by the specifications in Table 2. However, when the manuals for these models become available, we will review those requirements.

2. Transformation Processes Models

Many materials emitted into the atmosphere undergo not only physical dispersion but chemical changes as well. We need to know the whole life history of a pollutant, from emission through chemical and physical transformation to eventual removal, before accurately predicting the relationship of emission to air quality.

At present, the fate of six major pollutants is under investigation by modelers at Research Triangle Park and outside contractors under the guidance of the Chemistry and Physics Laboratory. The pollutants are

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Time resolution	1 hour
Spatial resolution	Point sources on UTM grid (±0.01 km) Area sources on variable grid from 1 km^2
Preferred medium	Tape
Units	Grams/second, watts
Source descriptors	Stack height (meters), exit velocity (meters/second), temperature (°K), stack diameter (meters)
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sulfur oxides, nitrogen oxides, hydrocarbons, oxidant, carbon monoxide, and particulates. The photochemical transformations have received the most attention so far. The emission inventory inputs into this model are listed in Table 3.

Table 3

EMISSION INVENTORY INPUT REQUIREMENTS
FOR THE TRANSFORMATION PROCESSES* MODEL

Content of inventory	SO_2, NO_x, O_3, CO, HC, particulates (NO_x by compounds; HC by categories, e.g., paraffins, olefins, aromatics)
Time resolution	1 hour
Spatial resolution	Point sources on UTM grid. Line sources (end points) in UTM coordinates. Area sources on variable-size grid from 1 km^2. Eulerian models utilize a fixed rectilinear grid, while Lagrangian models may require a flexible grid aligned along a given wind trajectory.
Preferred medium	Tape
Units	Grams, meters, seconds
Source descriptors	See Table 1
Temporal variations	Diurnal, daily, seasonal
Level of confidence	Depends on source data

*Principal candidate-model EPA contractors:

1. Systems Applications, Inc.
   Beverly Hills, California 90202
2. General Research Corporation
   Santa Barbara, California 93105
3. Pacific Environmental Services, Inc.
   Santa Monica, California 90403
4. Systems, Science & Software, Inc.
   La Jolla, California 92037

3. Mobile Sources

a. Surface Vehicles

Emissions from mobile sources such as automobiles, trucks, railroads, and vessels constitute an important segment of urban pollution. They account for virtually all of the carbon monoxide, the bulk of hydrocarbons, and a significant share of nitrogen oxides.

Since emissions from these sources are a function of the speed, number, and type of vehicles and the traffic patterns for given highway segments, they are best represented as line sources for heavily traveled streets. Lightly traveled areas can be considered area sources.

Emission inventory inputs into transportation-related models will require items indicated in Table 4. Emission requirements of models that treat vehicular sources have been limited to the requirements of mesoscale transportation modes. Microscale models--those treating near-source effects--may have more stringent emission requirements both in quantity, types, and precision of the data. Consequently, these

Table 4

EMISSION INVENTORY INPUT REQUIREMENTS
FOR VEHICULAR SOURCES MODEL

Content of inventory	CO, hydrocarbons (by types such as olefins, paraffins, aromatics), NO_x, particulates
Time resolution	1 hour
Spatial resolution	Street segments. Endpoints (in UTM coordinates), width (meters), center strip width (meters). Type of roadway at grade, elevated, cut section, street canyon. 1 km^2 (minimum) blocks for area sources.
Preferred medium	Tape
Units	Grams/second, meter
Source descriptors	Mean speed (meter/second), traffic volume by mix
Temporal variations	Diurnal, daily, seasonal
Level of confidence	Depends on source data (sampling, traffic counts, simulated traffic patterns, and the like)

types of highly specialized requirements are not within the scope of the basic inventory and will need to be obtained as a special task in conjunction with the particular microscale model experiments and evaluations.

b. Aircraft and Airports

Models dealing with pollutant emissions from planes on the ground level and above airports are also being developed. These are essentially microscale models dealing with the movement of individual aircraft during landings, taxiing, and takeoff. The degree of detail of emission data required for such a model (Table 5) is probably outside the scope of a regional inventory.

This work is coordinated by the Model Applications Branch of the Meteorology Laboratory, NERC, Research Triangle Park.

Table 5

EMISSION INVENTORY INPUT REQUIREMENTS
FOR MOBILE SOURCES (AIRPORTS) MODEL

Content of inventory	CO, hydrocarbons, NO_x, particulates
Time resolution	Every flight: taxiing time, takeoff and landing
Spatial resolution	Each runway, taxiway, gate, direction of takeoff
Preferred medium	Tape
Units	Grams/second, meter
Source descriptors	Type of plane
Temporal variations	
Level of confidence	

c. Railroads and Vessels

The contribution of railroads and vessels to the air pollution burden of the Saint Louis area is under investigation by the Transportation Center, Department of Transportation, Cambridge, Massachusetts.

The Center is conducting a study that will include a survey, an experimental program to obtain emission data and some dispersion modeling studies. In the course of this work, the Center will be both a user of and a contributor to the RAPS emission inventory.

The main pollutants of concern are SO_2 and particulates.

4. Other Studies

a. Particulate Emissions

Visibility loss caused by suspended fine particles is one of the most obvious manifestations of air pollution. Particles also may be involved in gas phase reactions and provide one of the mechanisms for the removal of nitrogen and sulfur oxides. Thus, the formation and removal of fine particles is part of our understanding of atmospheric reactions and will ultimately have to be accounted for in models describing such reactions.

Particles also play an important role in health studies, since those fine enough to remain suspended for indefinite periods (2 to 3 microns) are breathed in and can deposit in the lungs. Thus, there is a particular interest in this fraction of particulate emissions.

Studies are under way under the auspices of the Chemistry and Physics Laboratory, NERC-RTP, in the Saint Louis area to measure particle size distribution and their chemical analysis. Data on the emission of particles are needed, including data on size distribution of major sources. At the very least, data on the coarse (greater than 3μ) and fine (less than 3μ) fractions should be obtained.

b. Various Analyses

In addition to the modeling studies dealing with the physical characteristics of air pollution, such as emissions, air movement, or ambient concentrations of pollutants, the RAPS data are expected to be used for a number of studies and analyses dealing with the social, economic, and political impacts of air pollution and its control. Most of these studies will be based on long-term averages, and they do not require the fine resolution the RAPS inventory will provide. Still, they will profit from the increased accuracy of the new inventory.

The development of an inventory of the scope and detail of the Saint Louis study is in itself no mean achievement. On the basis of the experience gained in this study, guidelines for improved emission inventory procedures will no doubt be developed.

D. State and Local Control Agencies

The Metropolitan Saint Louis Interstate Air Quality Control Region comprises two states--Missouri and Illinois--and 12 counties. Five counties are in Missouri (Saint Louis City, Saint Louis, Saint Charles, Jefferson, and Franklin); seven are in Illinois (Bond, Clinton, Madison, Randolph, Saint Clair, and Washington). The Missouri counties are under the jurisdiction of the EPA Region VII office at Kansas City, Missouri. The Illinois counties are the responsibility of the EPA Region V office at Chicago, Illinois. Saint Louis City and Saint Louis County have separate air pollution control offices; the other Missouri counties are administered directly by the Missouri Air Conservation Commission at Jefferson City. The seven Illinois counties are under the jurisdiction of the Illinois Environmental Protection Agency. The area is shown in Figure 1. The crosshatched areas are those covered more completely by monitoring stations.

The ultimate purpose of the state and local control agencies is to achieve and maintain the air quality that corresponds to at least the national primary and secondary air standards, although states may establish more stringent standards. Thus, control agencies are concerned not only with pollution episodes (emergency conditions), but also with long-term pollution control programs aimed at a gradual reduction of air pollution levels and with community growth planning as it relates to added pollution. Ultimately, they are responsible for the effect of pollution on the health of the community, its vegetation, and perhaps even weather modifications.

1. City of Saint Louis

The Air Pollution Control Office, Department of Public Safety, City of Saint Louis, has a source evaluation section in charge of the emission inventory; it has identified some 16,000 point sources, but reliable data are available primarily for the large sources. The section's primary mission is enforcement rather than data collection.

The emission inventory is in the form of reports gathered by inspectors. The data were not computerized. See Table 6.

Table 6

EMISSION INVENTORY INPUT REQUIREMENTS
OF THE AIR POLLUTION CONTROL OFFICE,
CITY OF SAINT LOUIS

Content of inventory	SO_2 (HC, CO), NO_x, particulates
Time resolution	Yearly average output
Spatial resolution	Point sources, UTM coordinates
Preferred medium	Reports
Units	Engineering
Source descriptors	Stack height, exit velocity, temperature
Temporal variations	
Level of confidence	Inspectors' reports

2. Saint Louis County

The Air Pollution Control Division, Saint Louis County Health Department, like its Saint Louis City counterpart, is primarily an enforcement agency. It has identified the major pollution sources (about five that are emitting more than 100 tons per day, about 20 with emissions in excess of 25 tons per day). Some modeling of sulfur dioxide concentrations has been done, and some CO modeling is contemplated. The inventory (Table 7) is based on inspectors' reports. The control of additional pollution resulting from the growth of the area through proper land use is under consideration.

3. Missouri Air Conservation Commission, Jefferson City, Missouri

This agency has responsibility for the air quality of the state of Missouri. It operates through county or local air pollution control boards where such agencies exist, and it operates directly in other areas. Its function is to promulgate and enforce air pollution standards for the state of Missouri.

Table 7

EMISSION INVENTORY INPUT REQUIREMENTS
OF THE AIR POLLUTION CONTROL DIVISION,
SAINT LOUIS COUNTY HEALTH DEPARTMENT

Content of inventory	SO_2, NO_x, CO, HC, particulates
Time resolution	Yearly averages
Spatial resolution	Point sources on UTM coordinates
Preferred medium	Printout or tape
Units	Engineering
Source descriptors	Stack height, exit velocity, temperature
Temporal variations	None
Level of confidence	Major sources have been updated and some stack sampling is performed every six months

At present, the commission maintains data on particulates, SO_2, NO_x, total hydrocarbons, and CO. The data are based on an original survey carried out in 1968 (for particulates and SO_2 only), which has been updated in 1970 by IBM to include the other three pollutants. It was further updated in 1972 by Radian, Inc., and is now in National Emissions Data System (NEDS) format.

Emission input requirements are similar to those shown in Table 7 for Saint Louis County.

4. Illinois Environmental Protection Agency, Division of Air Pollution Control, Springfield, Illinois

The Illinois side of the Saint Louis Air Quality Control Region, which is heavily industrialized, is under the jurisdiction of the Illinois Environmental Protection Agency through its regional office (State Region IV, Collinsville) and the central office at Springfield. The Surveillance Section is in charge of the emission inventory, which is continually revised and enlarged. Currently it contains information on about 2,500 sources, but it is expected to reach 14,000 sources. The inventory is in the form of a computer printout, and it is used constantly as a guide

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for issuance of permits (surveillance), as a source of information to other agencies and interested parties, and as an aid in modeling. The modeling is contracted to Argonne National Laboratories, the State Implementation Plan is based on the Argonne work. Emission inputs are shown in Table 8.

Table 8

EMISSION INVENTORY INPUT REQUIREMENTS
OF THE ILLINOIS ENVIRONMENTAL PROTECTION AGENCY,
AIR POLLUTION CONTROL DIVISION

Content of inventory	SO_2, CO, NO_x, HC, particulates
Time resolution	Quarterly, seasonal Daily during air pollution episodes
Spatial resolution	Point sources: UTM coordinates ±0.1 km Area sources by counties
Preferred medium	Printout, tape
Units	Engineering
Source descriptors	Stack height, exit velocity, temperature
Temporal variations	
Level of confidence	

5. Federal Highway Department, Department of Transportation, 400 - 7th Street, N.W., Washington, D.C.

The Federal Highway Department, in cooperation with the Air Data Office of EPA, will conduct a study designed to provide information on driving patterns on highways in the Saint Louis area. This information, in combination with emission data based on different driving modes, will permit an accurate assignment of the contribution of automotive traffic to air pollution in Saint Louis. The emission inputs necessary for this study will have to be developed from dynamometer runs under simulated driving conditions for the pollutants of interest (CO, hydrocarbons, NO_x).

E. The Planning Agencies

1. East-West Gateway Coordinating Council

The East-West Gateway Coordinating Council (Laclede Gas Building, Saint Louis, Missouri) is a coordinating agency created to facilitate the land use and transportation planning for the Saint Louis metropolitan area. It helps to coordinate the planning efforts of the Missouri State Highway Commission, the Illinois Department of Transportation, and various county and city planning departments. It has also received support from the U.S. Department of Housing and Urban Development and the Federal Urban Mass Transportation Administration.

The council has produced a comprehensive Transportation Study Report analyzing present problems and suggesting long- and short-range solutions to transportation needs based on socioeconomic projections, analyses of present traffic patterns, and estimates of future travel demands. The council has generated an "Average Daily Traffic Volume Summary" for the Saint Louis metropolitan area (1970), which is updated yearly and constitutes a valuable source of information on mobile sources.

The council, thus, is both a source and a user of data on mobile sources. Additional traffic data are available from

- The Illinois Department of Transportation, 930 St. Clair Avenue, Fairview Heights, Illinois (Mr. Robert Kronst, District Engineer).
- The Missouri State Highway Department, State Highway Building, Jefferson City, Missouri (Mr. Carl Klam, Highway Engineer).
- The Saint Louis County Department of Highways, 120 N. Gay Street, Clayton, Missouri (Mr. Richard Daykin, Director).
- The Saint Louis City Traffic Department, City Hall, Saint Louis, Missouri (Mr. Jim Bauman).

2. Industrial Waste Control Council

The Industrial Waste Control Council is an association of pollution control officers from the major industrial firms in the Saint Louis area. As the problems they face are to some extent common to all of them, they share technical information and develop public relations. Their members are probably in the best position to develop emission inventories for their respective companies, inventories which they need to satisfy legal requirements. The data thus developed are generally confidential and available only to organizations empowered to receive them.

F. Research Programs

1. Metromex

Metromex is a joint program involving groups from Argonne National Laboratory, Battelle Pacific Northwest Laboratories, University of Chicago, Illinois State Water Survey, Stanford Research Institute, and the University of Wyoming. It is basically a federation of individual scientists with diverse sources of funding, but common or at least complimentary research interests in the inadvertent weather modifications produced by large urban complexes through the interaction of their emission of pollutants and their contribution to the energy balance of the area. The study is centered in the Saint Louis area. Pollutants of interest to Metromex are primarily suspended particulate matter. Thus, major sources of particles, their physical properties and chemical analysis, and their size distribution are all parameters of interest.

2. Community Health and Environmental Surveillance System

The Community Health and Environmental Surveillance System (CHESS) is a national program that relates community health to changing environmental quality. It consists of a series of standardized epidemiologic studies designed to measure simultaneously environmental quality and sensitive health indicators in sets of communities representing exposure gradients for common air pollutants. The program is conducted by EPA in cooperation with local public health agencies, universities, and private research institutes. The purpose of the CHESS program is

- To evaluate existing environmental standards
- To obtain health intelligence for new standards
- To document health benefits of air pollution control.

One of the areas under study is Saint Louis.

As mentioned earlier, CHESS, like other health effect studies, requires primarily ambient concentration data rather than emission data. At present, it obtains such data from its own network of air monitoring stations sited within each CHESS community. Eventually, RAPS data may be used. Since historical data on ambient concentrations are generally not available, estimates of past pollutant concentrations have to be based on past emission data from which estimated ambient concentrations are derived via meteorological dispersion models. Thus, CHESS has some need for emission data. The CHESS program is administered by the Human Studies Laboratory at Research Triangle Park. The Bioenvironmental Measurements Branch is responsible for obtaining exposure data for the use of epidemiologists. Compounds of interest to these studies are shown in Table 9.

Table 9

EMISSION INVENTORY INPUT REQUIREMENTS
FOR CHESS STUDIES

Content of inventory	SO_2, NO_x, particulates, especially sulfates, nitrates, and organics (size fractionated, if possible), hydrocarbons, O_3, CO, trace metals, e.g., Cd, Zn, Pb, Hg, Cr, V, Ni, Cu, Mn, asbestos, benzo-a-pyrene, PCB, pollens
Time resolution	For acute studies: 1 to 4 hours For chronic studies: cumulative exposures
Spatial resolution	School districts
Preferred medium	Printout
Units	Gram/centimeter/second
Source descriptors	
Temporal variations	Seasonal
Level of confidence	

3. University Research

Individual researchers at several of the universities in the study area are engaged in work requiring knowledge of pollutant levels. For example, at Washington University, Dr. Richard Gardener is conducting work in the area of thermal pollution--"heat islands"--and constructing an aerosol submodel in conjunction with other agencies. Dr. Christopher Hill is studying the total (mining, processing, use, and disposal) environmental impact of certain industries. At the Center for the Biology of Natural Systems, Dr. Charles Lee is establishing pollution burdens in rain and soil samples and in human tissues.

At Saint Louis University, Dr. Slavin is studying the relationship of air pollution to health problems. There seem to be strong correlations between airborne sulfates and asthma attacks, between SO_2 and emphysema, and between carbon monoxide and heart attacks. His department is collecting a daily pollen count and could make it available to the RAPS inventory.

At Southern Illinois University, Dr. Al Kahn is carrying out studies of the carbon monoxide and hemoglobin reactions.

As mentioned earlier in this report, these activities have only a peripheral requirement for emission data at this point. However, to a certain extent, the format of the inventory should be designed with the potential to accommodate such data if they should become necessary.

4. Plant Damage

There are a number of compounds in the atmosphere that cause vegetation damage either by reducing yield and growth or by affecting the quality of the crop. Well over 90 percent of the losses are caused by the following pollutants:[8]

- Ozone
- Peroxyacetyl nitrate (PAN)
- Oxides of nitrogen
- Sulfur dioxide
- Fluorides

Out of 65 standard metropolitan statistical areas, the Saint Louis metropolitan area is rated by Benedict[8] 16th with respect to potential damage due to hydrocarbons, 24th with respect to oxides of nitrogen, and 18th with respect to sulfur dioxide on a scale that takes into consideration total emissions, meteorological factors, area, and stagnation periods.

Thus, plant damage constitutes a significant aspect of air pollution in Saint Louis, something that should be taken into account in setting up the emission inventory. Data on oxidants--ozone, PAN, and

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oxides of nitrogen--and sulfur dioxide would normally be covered by the inventory. It may be advisable to make provisions for a fluoride inventory as well. The main known sources of fluorides are aluminum, phosphate, and ceramic plants.

G. Conclusions

The emission requirements data for RAPS are such that inventories taken for other purposes--such as the Implementation Planning Program (IPP) or air pollution control agencies--are inadequate mainly in the degree of detail required for modeling studies. Since the verification of atmospheric dispersion models is an early and major goal of RAPS, the requirements of the modelers constitute the most important criterion of the adequacy of the inventory.

The most important requirements for modeling are

- Pollutants
  - From stationary sources: SO_2, CO, particulates, NO_x.
  - From mobile sources: CO, NO_x, particulates, hydrocarbons (by types).
- Resolution
  - Temporal: 1 hour
  - Spatial: Point sources--0.01 Km.
    Area sources--variable size grid from 1 kM^2 to 16 Km^2.
- Units. Depends on model, but always metric.
- Output programs. Depends on model. Inventory should provide FORTRAN interface. Output to include source descriptors such as location (UTM coordinates), stack height, exit temperature, and velocity. For traffic models, description to include descriptors of roadway.
- Area. The area to be covered coincides with the boundaries of the Metropolitan Saint Louis Interstate Air Quality Region. Alternatively, it could be resolved to a smaller, more central area covering only the City of Saint Louis and the Counties of Saint Charles, Jefferson, Saint Louis, Monroe, Madison, and Saint Clair (Figure 1).

- Time. The period will vary considerably. In some cases, model verifications will be limited to relatively short periods (48 to 72 hours).

The requirements of other study groups, such as the health study workers, are more extensive, but generally less intensive. They require the system to store and retrieve information on many compounds, but the demands for spatial and particularly temporal resolution are much less critical.

Special programs, such as Metromex, have specific requirements for certain categories of pollutants, which may or may not be satisfied by a general emission inventory.

SC553.T017FR

REGIONAL AIR POLLUTION STUDY
TASK ORDER NO. 17
FINAL REPORT

SPECIAL EMISSION INVENTORIES FOR FIELD STUDIES

CONTRACT 68-02-1081

Prepared for

Environmental Protection Agency
Office of Air Quality Planning and Standards

National Air Data Branch
Durham, N. C.

by

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SPECIAL EMISSION INVENTORIES FOR FIELD EXPERIMENTS

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I. INTRODUCTION

A basic component of the St. Louis Regional Air Pollution Study (RAPS) is a data base containing detailed information on the emissions of pollutants, micro-meteorological conditions, and ambient concentration of pollutants in the St. Louis area.

Although the information contained in the resulting data bank is far more detailed than other available data, in special situations an even more detailed or accurate breakdown may be required. The gathering of such special information with regard to emissions is dealt with in this report.

The report describes the background of the Regional Air Pollution Study and the content of existing emission inventories. It discusses briefly the possible additional emission inventory requirements of field studies and details the procedures to be followed in obtaining this information.

II. BACKGROUND - THE REGIONAL AIR POLLUTION STUDY (RAPS)

With the enactment of the Clean Air Act as amended (1970), the attainment of minimal pollution levels became a national goal. Since the pollution levels in most metropolitan areas exceed one or several of the Ambient Air Standards as established by this Act, the control and reduction of man-made pollution became a necessary step toward this goal.

The establishment of emission standards assumes an understanding of the relationship between the emission of pollutants by industrial, commercial, and private sources on one hand, and the resulting level of ambient concentrations on the other. This relationship is defined by emission, transport, transformation and removal processes, which differ for each pollutant and are only partially understood. As a consequence, the mathematical description of these relationships -- the mathematical simulation model -- can deal only with gross features of the above processes, with the result that only imprecise answers are forthcoming.

The control of emissions is a costly process, not only in money but also in the wider impact on the social life and features of a community, as exemplified by the requirement to reduce automotive traffic by 80-90% in certain communities to attain the standards prescribed by law. Thus, the development of comprehensive and, above all, reliable models is an urgent requirement in any rational approach to the emission control problem.

A considerable number of air quality models has been developed, ranging in scope from relatively simple ones dealing with a single point source plume to those dealing with as complex a system as an urban area. Very few of these have been extensively tested in the field to establish their accuracy, and fewer yet have provided sufficiently accurate values when so tested. A significant portion of the difficulties may well be not so much with the models themselves, but rather with the test data.

In the past, air pollution studies have been hampered by the paucity of test data. Real time emission data are just about non-existent; meteorological data are generally gathered (usually for different purposes) at weather stations miles away from the test area, such as at airports, and a relatively small number of spot tests of ambient pollution concentrations, which could be obtained within the usual financial constraints of such studies, might not provide really representative data.

In the planning of RAPS, care was taken to overcome these shortcomings. Clearly, what is needed for these purposes is a comprehensive, regional data base. Air quality is determined by regional topographic and meteorological features and the associated human activities rather than by political boundaries; thus, a regional approach encompassing a reasonably self-contained air basis is required. Both ambient and emission data should be available on a real time basis for the same time period, preferably for a sufficiently long period to encompass a variety of meteorological conditions. And finally, the area chosen should be devoid of unique features which would bias the results and make their application to other areas inappropriate.

Out of such considerations, the RAPS concept was born. The St. Louis area was chosen as having the most appropriate characteristics of the 33 Standard Metropolitan Statistical Areas of more than 400,00 population and the project initiated by the establishment of a Regional Air Monitoring Station (RAMS) network, which will provide on a continuous basis detailed meteorological and pollutant data from 25 stations. The remaining data necessary for the completion of the data base are emission data, gathered and stored in the RAPS Emission Inventory.

III. THE RAPS EMISSION INVENTORY

Several inventories exist for the Metropolitan St. Louis Interstate Air Quality Control Region; indeed, the existence of historical data was one of the considerations in the choice of St. Louis for the RAPS study. Initially the inventory contained only data on SO_2 and particulates; more recent inventories include carbon monoxide, hydrocarbons and oxides of nitrogen as well. Table I shows a comparison of these inventories. Of these, the National Emission Data System (NEDS) inventory is most up to date.

The data contained in these inventories are of varying origin and reliability, ranging from answers to questionnaires to inspector's reports and actual stack measurements (though there are very few of the latter). In all cases the data are based on annual consumption, production, or emission estimates. While these figures may be satisfactory for some purposes, they do not provide the necessary accuracy for model verification studies; the data fed into a model run should be of equal quality, i.e., hourly measured values, whether they pertain to meteorological variables, ambient concentrations, or stack emissions.

In the past, because of the limitations imposed by the scope and funding of earlier studies, modelers relied heavily on emission models; that is, mathematical expressions or algorithms which converted the annual values to hourly ones. These models have ranged from simple averaging to complex expressions based on typical load or production patterns, ambient temperatures (degree-days), and the like. Indeed in some areas, notably for emissions from mobile sources such as automobiles, emission modeling is the only feasible approach. Such modeling cannot, however, be expected to product an inventory having the accuracy and resolution required for model verification studies of point sources.

FIGURE 1**

COMPARISON OF EMISSION INVENTORIES FOR THE
METROPOLITAN SAINT LOUIS INTERSTATE AIR QUALITY REGION*

Inventory Name	Data Base Year	Area*	Emission Inventory Technique	Emission Totals (tons/year)				
				Sulfur Oxides	Partic-ulates	Carbon Monoxide	Hydro-carbons	Nitrogen Oxides
IPP	1968	Franklin County not included	IPP forms filled out by local agencies from questionnaires (Mo.) or letters of intent (Ill.)	612,318	192,800			
IBM	1970	Madison County, Franklin County, Saint Clair County and Monroe County not included	IPP point source data (1968) updated)		Not	comparable		
DAQED	1967 to 1968	Franklin Count, and Monroe County not included	Rapid survey	662,490	186,290	1,644,640	326,280	180,780
NATO -1	1969	----	Updated IPP data	746,160	185,910	1,417,460	187,650	218,610
NATO -2	1969	----	Updated IPP data New emission factors	744,930	184,970	1,865,720	288,430	295,340
NEDS	1973	----	Updated IPP data	757,105	347,379	3,803,460	282,982	298,491

*Includes the following jurisdictions, except as noted: Jefferson County, Saint Charles County, Saint Louis County, St. Louis City, Franklin County, Madison County, Monroe County, Saint Clair County.

**Source: A Regional Air Pollution Study (RAPS) preliminary emission inventory Stanford Research Institute, EPA Contract No. 68-02-1026.

The RAPS emission inventory was designed to fill this need. It will consist of hourly emission data gathered by several methods. Point sources were grouped into two major categories:

Group I - Data from this group, which includes sources emitting more than 1000 tons pollutants per year, were gathered on an hourly basis. The data are based on *measured* emission, consumption or process records, which could be directly translated into weight emissions of pollutants.

Group II - This group includes point sources (mainly smaller ones) from which hourly data were not obtained. Hourly values were calculated from yearly or other long-term data using appropriate weighting procedures.

The conversion of primary data, such as fuel consumption, to mass flow of pollutants was accomplished using emission factors. The starting point for these calculations were compilations of available emission factors, particularly EPA Publication AP-42 "Compilation of Air Pollutant Emission Factors," 2nd edition (1973). In as many cases as possible, the factors were established by source testing in order to provide the highest accuracy obtainable. This is particularly necessary for such pollutants as NO_x and CO, which are not closely related to fuel analysis.

The RAPS inventory initially concentrated on sources of SO_2, as this compound was of primary interest to the modeling of the dispersion of effluents from stationary point sources. Data are recorded as mass effluent per hour for sources emitting in excess of 1000 tons of SO_2 per year. Data for smaller sources, that is those emitting between 1000 and 100 tons of SO_2 per year, were calculated based on annual emissions as determined from current dates, and a distribution function derived from both space heating and manufacturing data similar to those used by Roberts *et al*.(1)

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(1) Roberts, J. J. *et al*, Chicago Air Pollution Systems Analysis Program, Argonne National Laboratory ANL/ES-CC-007.

The RAPS emission inventory system is capable of storing data based on total annual emissions in a manner which directly reflects the estimates of hourly, weekly and monthly variations.

A precision analysis to determine the range of accuracy of the data (and assumptions) used will be performed as a separate task.

Data for other effluents from point sources will be handled and stored in a similar manner. Data for emissions from area sources (e.g., residential areas) and line sources (e.g., highways, railroads) were calculated and are similarly recorded on an hourly basis. Thus, the RAPS inventory contains the following information on emissions:

- Measured hourly values of pollutants (initially only SO_2) emitted by major point sources.
- Calculated hourly values for pollutants for smaller point sources.
- Location by street address and UTM coordinates and stack data for all point sources.
- Calculated hourly values for the emission of pollutants from area sources.
- Calculated hourly values for emissions from line sources.

In addition, of course, the RAPS inventory also contains the ambient concentrations of pollutants and detailed meteorological information provided by the RAMS network. A detailed overview of the RAPS Emission Inventory characteristics is contained in a recent EPA report(2).

Thus, field studies requiring a finer time resolution than one hour, more accurate emission data, or additional information on smaller sources have to rely on the gathering of a special emission inventory.

IV. RAPS DATA HANDLING AND STORAGE

All RAPS data, whether they pertain to emissions, ambient concentrations of pollutants, or meteorological conditions, are permanently stored in memory banks in a Univac 1100 computer located at EPA-Research Triangle. A data management system -- System 2000(3) -- provides the basic functions of file definition, addition, deletion and revision of data items, retrieval of selected items, hierarchic sorting by content, and output of specific data components in specified formats to construct files for use in other programs. System 2000 has Fortran interfaces. Since all presently existing air quality models are written in Fortran, appropriate output programs can be written to access the inventory files and write data in the formats required by the model. Because of the widely varying requirements of the models, these programs will have to be written and supplied by the users.

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(2) "A Regional Air Pollution Study Preliminary Emission Inventory", U. S. Environmental Protection Agency No. EPA-450/3-74-030, January 1974.

V. SPECIAL EMISSION INVENTORIES

In addition to the main thrust of the RAPS program, which is aimed at dispersion modeling verification, a large number of other studies will be carried out under the RAPS umbrella. These so-called field studies will supplement the ongoing RAPS measurements and provide data in related fields. Some will deal with meteorological problems; others address themselves to the study of aerosols, measurement techniques, and photochemical reactions.

It is likely that some studies will require either more accurate data -- for example, measured emissions from a relatively small source situated in the vicinity of the experiment -- or a shorter time resolution than one hour; for example, a detailed traffic count during rush hours, which might require a ten-minute resolution.

If it appears that more detailed or real time emission data will be needed for a study, the information will have to be obtained as part of the field study, using, if possible, the methodologies developed for the particular type of emissions. It will, therefore, be necessary to allow for the necessary effort in terms of both time and expense as part of the study.

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(3) MRI Systems Corporation, Austin, Texas.

A. Survey of RAPS Methodologies and Data

The first step is, of course, a survey of available information. The RAPS Emission Inventory Handbook contains detailed descriptions of all emission-related information on RAPS, including a discussion of pollutants, sources, emission models and data availability. The handbook should, therefore, be used as a basis for the planning of special inventories. If available data prove to be inadequate, additional information will have to be obtained in the particular area of interest to the investigator. Generally, emission data are classified into three such areas:

1. Point Sources
   - Combustion sources
   - Evaporative sources
   - Process emissions
2. Area Sources
   - Domestic, commercial and industrial heating
   - Distributed industrial and commercial emissions
   - Distributed traffic emissions
3. Line Sources
   - Cars and trucks - principal highways

The methodologies used to obtain such inventories are discussed in the RAPS Emission Inventory Handbook, including the following methodologies:

1. Point Source Methodology and Inventory
2. Stationary Area Source
3. Highway (Line-Source) Methodology
4. Highway Area Source Methodology
5. Vessel Methodology and Inventory
6. Railroad Methodology and Inventory
7. Airport Methodology and Inventory
8. Off-highway Mobile Sources
9. Hydrocarbon Emission Methodology
10. Heat Emission Methodology
11. Fugitive Dust Methodology

B. Definition of Requirements for Special Data

If the survey of existing RAPS data indicates that special data will have to be acquired, the nature of the additional data has to be defined. The data required by the investigator may require better time or spatial resolution, real time rather than calculated data, or higher overall accuracy than data available in the RAPS inventory. For example, the modeling of emissions from mobile sources during the rush hours may require a five to ten minute resolution for a two-hour period. Alternatively, it may be necessary to monitor the actual emissions of a certain stack by stack-analysis because of its overriding influence on a given receptor or experiment.

The exact requirements have to be spelled out by the investigators and will form the substance of the Work Statement of a Task Order issued to cover these requirements. The objectives of the study should be described (in the overall context of RAPS) as well as the method of approach, which defines the requirements for additional emission data.

C. Request for Task Order Assignment

Once the nature of the additional data requirement has been specified, a request for a task order assignment has to be made by the investigator. The request is directed to the Contracting Officer, RAPS, St. Louis. The request must spell out the work required, the estimated man hours, and the source of funding. It is important to note the investigator will have to supply the funding for these task orders. Sufficient time has to be allowed for the task order to be issued, processed by the general contractor, and approved to the RAPS Contracting Office. On the average, this process might take about 60 days. A sample task order is shown in Figure 2.

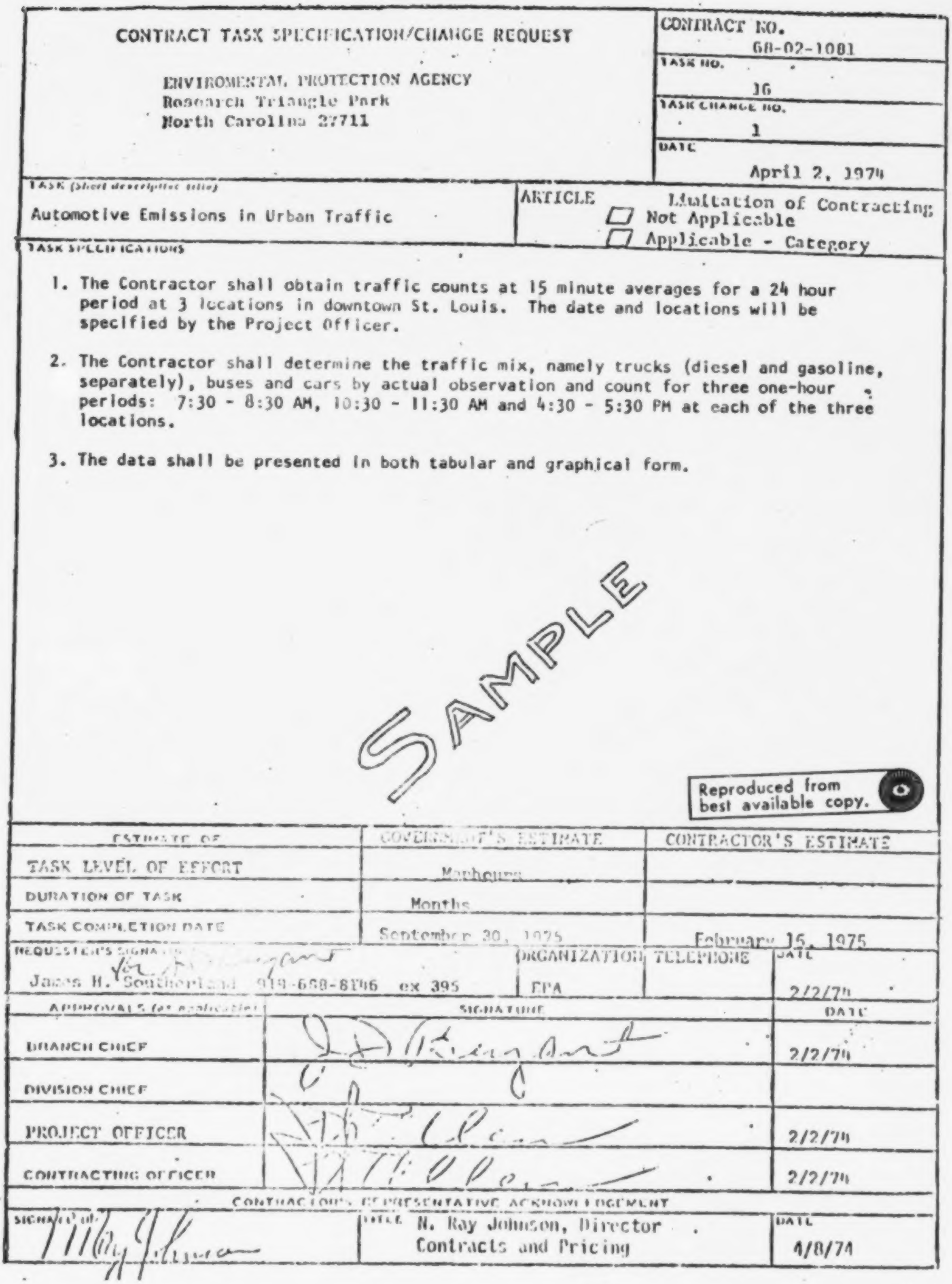
D. Task Order Execution

In subsequent sections, the execution of typical task orders is briefly discussed to describe the nature of emission data collection and the time element associated with it.

1. Source Identification and Contact. After the nature of the required data has been determined by the investigator, the emission source has to be identified by the investigator also.

FIGURE 2

SAMPLE TASK ORDER



CONTRACT TASK SPECIFICATION/CHANGE REQUEST

ENVIROMENTAL PROTECTION AGENCY
Research Triangle Park
North Carolina 27711

CONTRACT NO. 68-02-1081
TASK NO. 16
TASK CHANGE NO. 1
DATE April 2, 1974

TASK (Short descriptive title): Automotive Emissions in Urban Traffic

ARTICLE Limitation of Contracting
☐ Not Applicable
☐ Applicable - Category

TASK SPECIFICATIONS

1. The Contractor shall obtain traffic counts at 15 minute averages for a 24 hour period at 3 locations in downtown St. Louis. The date and locations will be specified by the Project Officer.

2. The Contractor shall determine the traffic mix, namely trucks (diesel and gasoline, separately), buses and cars by actual observation and count for three one-hour periods: 7:30 - 8:30 AM, 10:30 - 11:30 AM and 4:30 - 5:30 PM at each of the three locations.

3. The data shall be presented in both tabular and graphical form.

SAMPLE

Reproduced from best available copy.

ESTIMATE OF	GOVERNMENT'S ESTIMATE	CONTRACTOR'S ESTIMATE
TASK LEVEL OF EFFORT	Manhours	
DURATION OF TASK	Months	
TASK COMPLETION DATE	September 30, 1975	February 15, 1975

REQUESTER'S SIGNATURE: for J. D. Bryant — James H. Southerland 919-688-8146 ex 395
ORGANIZATION: EPA
TELEPHONE:
DATE: 2/2/74

APPROVALS (as applicable)	SIGNATURE	DATE
BRANCH CHIEF	J. D. Bryant	2/2/74
DIVISION CHIEF		
PROJECT OFFICER		2/2/74
CONTRACTING OFFICER		2/2/74

CONTRACTOR'S REPRESENTATIVE ACKNOWLEDGEMENT

SIGNATURE OF: N. Ray Johnson
TITLE: N. Ray Johnson, Director Contracts and Pricing
DATE: 4/8/74

The source could be private, such as an industrial stack, a utility, such as a power plant, or even public, as for example a municipal incinerator or traffic information, In each case, the appropriate management or authority has to be contacted and their cooperation obtained. In a sense, RAPS is a community service project, an in-depth study of the air pollution problem in St. Louis. Because of this, cooperation from the citizenry can be expected and has, in fact, been forthcoming.

After agreement is reached on the problems of access of the information, the detailed mechanism for data collection has to be worked out. It should be born in mind that as much as possible of this task should be performed by the contractor, and only minimal demands should be made on the ongoing operations. This means that if monitoring equipment is required, it has to be supplied, installed, and probably operated by the contractor. The Task Order has to allow for the resulting cost.

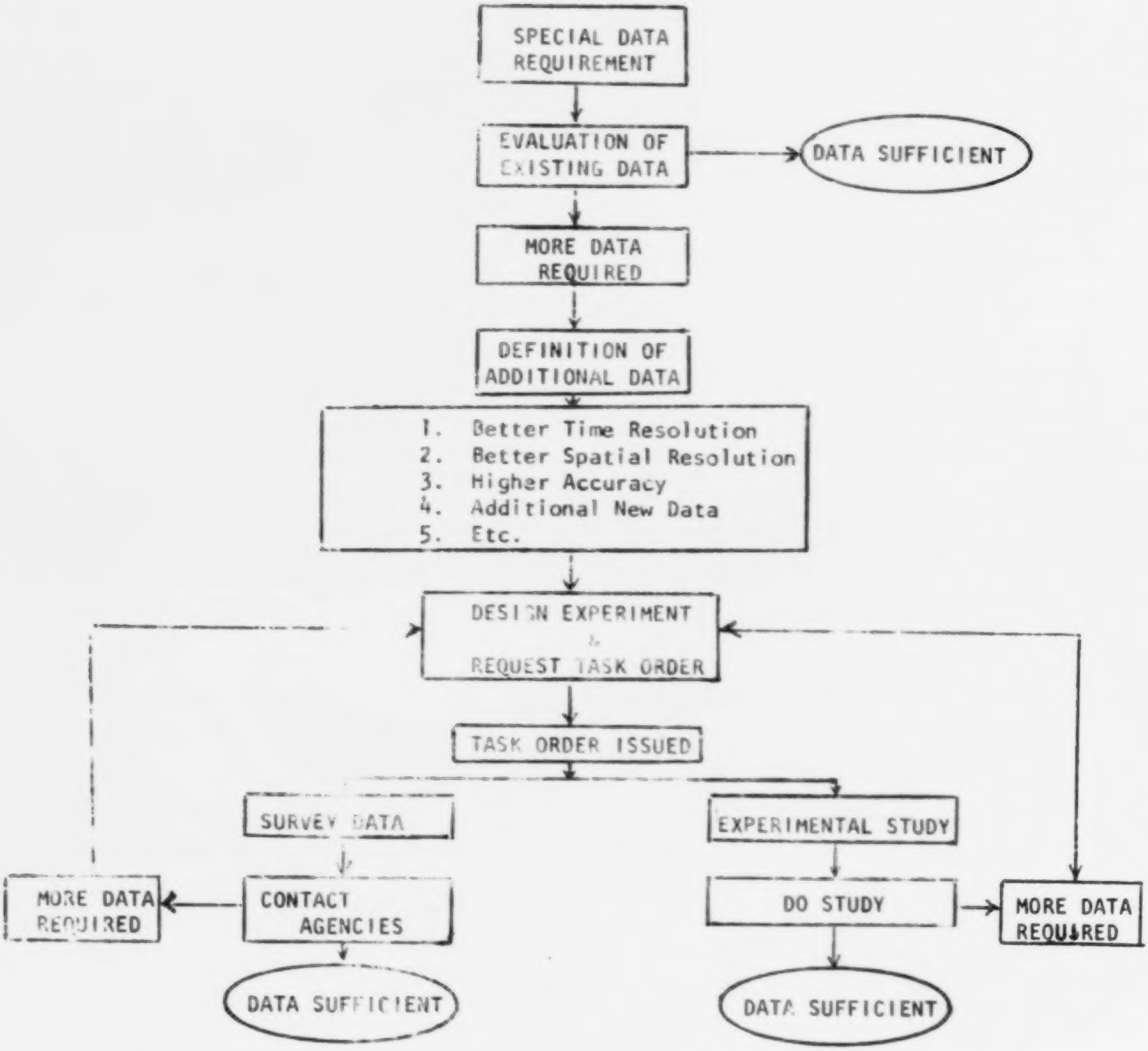
2. Sample and Data Collection. The nature of the required additional data determines the kind of information to be gathered, which may range from traffic counts to utility bills or to stack sampling. In general, the methodologies listed earlier will provide a starting point.

As an example, consider a model validation experiment which requires an actual traffic count at specified locations for a 24 hour interval, with a 15 minute time resolution. It also requires verification of the vehicle mix. (Step 1, Fig. 3, Flow Chart for Special Emission Inventory, P. 14.) Available data only provide averages based on annual counts and traffic mix is assumed to correspond to vehicle registration figures (Step 2). Thus, data for 15 minute intervals and the determination of the traffic mix will have to be obtained experimentally at the designated locations (Step 4). These requirements are then spelled out in a Task Order, which reflects the experimental design as noted in Figure 3 (Step 5). The Task Order might read as shown in Figure 2:

The time element of obtaining emission data is important, since considerable time is required for the preliminary steps and equipment preparation and calibration. In general, it might take

FIGURE 3

FLOW CHART FOR SPECIAL EMISSION INVENTORY


SPECIAL DATA REQUIREMENT
EVALUATION OF EXISTING DATA
DATA SUFFICIENT
MORE DATA REQUIRED
DEFINITION OF ADDITIONAL DATA
1. Better Time Resolution
2. Better Spatial Resolution
3. Higher Accuracy
4. Additional New Data
5. Etc.
DESIGN EXPERIMENT & REQUEST TASK ORDER
TASK ORDER ISSUED
SURVEY DATA
EXPERIMENTAL STUDY
MORE DATA REQUIRED
CONTACT AGENCIES
DO STUDY
MORE DATA REQUIRED
DATA SUFFICIENT
DATA SUFFICIENT

- 4 - 6 weeks (elapsed time) for a data survey
- 1 - 2 weeks for source identification and contact
- 2 - 4 weeks for equipment preparation and calibration
  (not including delivery time for new equipment)
- 1 - 2 weeks for stack sampling
- 1 - 2 weeks for sample analysis
- 1 - 4 weeks for data interpretation

Thus, even a relatively minor emission data acquisition will require from 10 to 22 weeks (elapsed time). The manpower requirement varies considerably: the survey and preliminary work can be performed by one person; the actual experimental work depends on the size and complexity of the source and might require from two to four people (very large sources, such as power plants, might require up to 20 people). The field crew usually needs a laboratory backup of perhaps two more people for instrument calibration and checkout, as well as chemical analysis. An average stack analysis might require on the order of 300 man hours. A flow chart indicating the sequence of events is shown in Figure 3.

SUMMARY AND CONCLUSION

This report briefly outlines the background and present status of the emission inventory for the St. Louis area, with special reference to unique requirements of some of the field experiments planned during the Regional Air Pollution Study. The nature of the existing data is indicated, and a procedure for obtaining additional information is outlined.

EPA-450/3-75-026

PRESENTATION OF NEDS EMISSION DATA FOR AIR POLLUTION STUDIES

by

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Contract No. 68-02-1096, Task 5

EPA Project Officer: Charles C. Masser

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, N. C. 27711

November 1974

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INTRODUCTION

The National Air Data Branch (NADB) is functionally a part of Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards of the Environmental Protection Agency. This organization has the responsibility to gather source emission, air quality, and related information from 55 states and territories into a single national air data management information system at one location under one administrative body. The Branch's activities include management of air quality emissions data in the National Emissions Data System (NEDS) and the Storage and Retrieval of Aerometric Data (SAROAD) systems collectively referred to as the Aerometric and Emissions Reporting System (AEROS). The information provided by these systems is utilized by EPA management in decision-making processes involving evaluation of trends in air quality and emissions and subsequent development of control strategies, and for assessing economic effects and cost/effectiveness of proposed and promulgated control legislation, regulations, and abatement alternatives.

Emissions information for more than 75,000 point sources is collected and analyzed by NEDS. This system also handles area sources and other related information necessary for emission inventories and to reflect federal reporting requirements.

NADB also has the capability to access information gathered under the EPA Compliance Data Systems (CDS), Hazardous Air Pollutant Enforcement Management System (HAPEMS), and Comprehensive Data Handling System (CDHS).

The emissions and source inventory data bank (in NEDS) was established in early 1972. Contributors to the data bank are primarily the U.S. Environmental Protection Agency and other Federal, State, and local agencies; and to a small extent, private groups and institutions. The normal flow of domestic data is from State and local agencies to EPA Regional Offices and then to the NADB. Data are validated and authenticated preparatory to storage in the data bank.

Through the use of NEDS the Branch produces (1) semiannual emission reports to the Administrator of EPA and for publication, (2) data and summary printouts to the contributing agencies, (3) reports on analyses of particular data of interest, (4) responses to special requests, and (5) information used as input to air quality simulation models.

The purpose of this presentation is to provide researchers in the field of criteria air pollutant emissions with a background of what data are available in NEDS, both in edited form and in summaries, and what types of summaries and analyses are included with short discussions of the method of preparation of each and some of the required and/or optional input parameters associated with each.

It is important to note that this presentation is neither exhaustive nor complete. That is, only a brief description of each item is included; recourse to cited documents or to NADB is recommended for further information. Also, this presentation is incomplete with regards to the availability of either data, summaries, or analyses. The NEDS data base is frequently updated to include (a) new or existing but previously unidentified emission sources; (b) additions or corrections to existing emission sources (this includes achievement of a compliance schedule milestone); (c) new emission sources moving from planned to active status;

(d) existing emission sources which cease operation; and (e) new sources in the planning/construction/startup phases. Furthermore, new summary and analysis procedures are continually being prepared and old ones are revised as new user needs are identified. NADB would be pleased to receive requests for its services and solicits ideas on improving the effectiveness and usefulness of NEDS.

RETRIEVAL OF NEDS DATA

The NEDS currently includes identifying data and criteria pollutant emissions values for each of over 75,000 point sources as well as emissions and location data for about 3,200 "area sources" (counties, etc.). What follows in this section is a discussion of the products of the retrieval programs currently available in NEDS. As noted previously, this is not necessarily a complete list, since NEDS is continually being added to and modified.

The basic retrieval program for the "general user" produces the standard format listings which display all relevant descriptive and identifying data as well as estimated and NEDS calculated emissions, for each criteria pollutant. Computer output on each page consists of data for each process emission source or two county area source entries. The interested user is encouraged to refer to APTD 1135, "Guide for Compiling a Comprehensive Emission Inventory," for a detailed description of source emission data requirements. This reference will soon be entirely superseded by the AEROS manual.

In addition to standard-format complete point and area source listings, abbreviated listings identifying point sources can be produced which display emission-related characteristics and annual emissions for each of the five criteria pollutants (Particulates, Sulfur Oxides, Oxides of Nitrogen, Hydrocarbons, and Carbon Monoxide). These listings are available with the following parameters for selection:

1. AQCR, county, state, EPA region, nationwide; multiple AQCR's, states, or counties may be requested for a single run.
2. Ownership (private, Federal Government, local government, utility, or all).
3. Minimum requested value of emission in tons/year for any one pollutant (≥ 0).
4. Source Classification Code (SCC), (at any of the four classification levels which are essentially process descriptors).
5. Inclusion or exclusion of confidential data.
6. Standard industrial Classification (SIC) code.
7. Emission estimation method.

The selected data can then be sorted in ascending (A) or descending (D) sequence for any of the following data values:

1. State (A)
2. County (A)
3. Plant Number (A)
4. Point Number (A)
5. Source Classification Code (A)
6. Ownership (Federal, local government, utility, or all) (A)
7. Standard Industrial Classification (SIC) Code (A)
8. Emission Estimation Method (A)
9. AQCR (A)
10. Plant Name (A)
11. Amount of emissions for any one of the five criteria pollutants (A)

12. Year of Record (A)

13. Control equipment (A)

14. Control Efficiency (D)

15. Fuel Sulfur Content (D)

16. Fuel Ash Content (D)

17. Major City Code (A)

18. UTM Coordinates (D)

19. Operating Rate (D)

20. Confidentiality (A)

Both of these lists are expanding as users' needs expand.

DATA SUMMARIES

Because of the large amount of data in the NEDB, many users find it desirable, and entirely adequate for their needs, to have one or more summaries of the emissions data contained in the data base. NEDS has several summaries available, of which the Emissions Report and "Fuel Use Report" are frequently used.

One example page of condensed point source listings selected by: minimum acceptable emission value = 0 and AQCR = 70, and sorted by SCC Code, is shown in Figure 1. An example page selected by the same criteria and sorted by particulates emission values is shown in Figure 2.

Total emissions by pollutant for the five criteria pollutants selected by total U.S., EPA region, state, AQCR, state portion of interstate AQCR's, and county are available in summary form. Examples are presented in Figure 3 by county and in Figure 4 by AQCR as sub-totals at Levels I, II, and/or III of the SCC for point sources and corresponding area source sub-totals.

Total fuels used by fuel-consuming stationary source categories are also available in summary by total U.S., state, county or AQCR. Examples are presented in Figure 5 by county and Figure 6 by AQCR, for AQCR 70.

Additional summaries are available, and more summaries are added as user needs dictate. Please contact the National Air Data Branch for more information and assistance with any particular needs.

THE WEIGHTED STATISTICAL ANALYSIS PROGRAM (WSAP)

The purpose of this program is to identify analytically the NEDS emissions source categories which require the most accurate and complete data in order for NEDS to maintain an overall level of accuracy in total emissions reported. It also calculates the accuracy required of each of the sub-categories and elemental categories in order to meet an overall accuracy level (specified by the user of WSAP).

Input parameter requirements are: the AQCR, state, or county desired, and the desired confidence level (maximum permissible percentage error in total emissions) for each of the five criteria pollutants (variables designated as THETA's in the program output). The appropriate emissions report values for each pollutant in the summary are used as data. The program then calculates allowable errors for each pollutant by magnitude and percentage for all entries in each succeeding level of the "tree" of emissions. The algorithm used is the standard linear statistical model, in which (a) the sum of the partial emission $(\bar{\tau}_i)$ equals the total emissions, $(\bar{\tau}_T)$, (b) the total allowable error (σ_T) is THETA times the total emission (τ_T), (c) the sum of the variances (σ_2^2) of the partial emissions is equal to the variance (σ_T^2) of the total emissions and (d) the variances (σ_2^2) of the partial emissions are proportional to (weighted by the partial emission $(\bar{\tau}_i)$. Mathematically,

(a) $$\bar{\tau}_T = \sum_i \bar{\tau}_i$$

(b) $$\sigma_T = \theta \bar{\tau}_T$$

(c) $$\sigma_T^2 = \sum_i \sigma_i^2$$

(d) $$\frac{\sigma_i^2}{\bar{\tau}_i} = \frac{\sigma_T^2}{\bar{\tau}_T} \text{ for all } i.$$

The σ's calculated at each "tree" level are used to derive THETA's for the next detailed level of calculation until all elementary categories in the emissions report summary have been assigned their THETA's.

A sample of two neighboring levels of iteration from the report for AQCR 70 (Metropolitan St. Louis Interstate) is shown in Figure 7.

GRAPHICAL PRESENTATION OF NEDS DATA

It is often useful to condense large amounts of data into a graphical format. Consider as examples the graphs presented as Figures 8-17. All were drawn from the data sampled in Figure 2 and the corresponding listings for AQCR 070 for the other four criteria pollutants. Figures 8-12 show that, generally, a significant number of large point sources exist for the criteria pollutants, but that the number of sources rises rapidly as the amount emitted per source decreases. The one exception in these examples is hydrocarbons, in that very few large sources exist. Figures 13-17 display the same data in a different format; they show that 75% or more of point source emissions are caused by the 10 largest emitters for each pollutant except hydrocarbons. With hydrocarbons, approximately 80 sources produce 75% of the point source emissions. Thus, for the non-hydrocarbon point sources a significant percentage of total emissions can be attributed to very few sources. Correspondingly for hydrocarbon emissions a much larger percentage of sources is needed to accumulate a similar percentage of total emissions.

GRIDDING AND EMISSION APPORTIONING FOR COUNTIES AND EMISSION DENSITIES

What has been presented in detail thus far has dealt with point source emissions. Point sources are generally defined as stationary emission sources emitting 100 tons or more per year of at least one criteria pollutant. The remainder of identifiable sources include mobile sources and "small" stationary sources and are classed as area sources. They are large in number, however, and usually contribute significantly to total emissions of criteria pollutants, especially in urban and suburban areas. In the area source emission methodology area-wide fuel totals are used. If large point sources are not included in the point source listing they are included in the area source total. As the point source inventory is improved and more sources under 100 tons per year are included, the area source emissions will correspondingly decrease. Area sources are included in NEDS as measures of inputs to emission production in a geographic area (such as a county) for various economic categories, such as type of fuel used by use category; for example, residential heating with fuel oil or heavy-duty vehicle use of diesel fuel. If the user wishes to model air quality, say, using a dispersion modeling technique such as the Implementation Planning Program (IPP), over an area which includes only one or a few area sources (one NEDS record for each area source), it is necessary, for adequate definition in the model, to apportion the area source emissions into geographically smaller sources which are treated as "virtual" point sources by the IPP model. Gridding of the total area being modeled into smaller areas and the apportioning of the total area source emissions to the smaller resultant grid areas is essentially what is required in this case; what follows is a description of one such technique and its usefulness in the graphical display of emissions for a geographic area or political jurisdiction.

The Computer Assisted Area Source Emissions (CAASE) gridding system of programs provides the user with assistance in gridding a county and apportioning area source emissions to the grid squares preliminary to modeling the area with a dispersion model such as the Implementation Planning Program (IPP). A complete description of the program and the CAASE technique is included in the "Computer Assisted Area Source Emissions (CAASE) User's Guide" (EPA-450/3-74-035). The NEDS area source record for the City of St. Louis, Mo., in AQCR 070 is shown in Figure 18. In the IPP, each grid square is treated as a virtual point source, and specific point sources are also modeled to provide a total annual mean air quality display. If care is used in the gridding process, several counties may be combined into a larger unit such as an AQCR if desired. Primary outputs from the CAASE system include IPP area source input cards; a sample listing of these cards is shown in Figure 19.

Since the gridding process applied to AQCR 070 produced a large number of area sources (AQCR 070 is a large-area, densely-populated region), it is useful to provide some form of graphical display to compactly characterize the AQCR's emissions pattern. For example, an "emission density" (emission/unit area) plot can display the relative concentration pattern of emissions associated with the area, assuming that the apportioning techniques are appropriate. Accordingly, rank-ordered listings of area source emission/unit area for all grid squares for each criteria pollutant were prepared. Graphs of cumulative percent of emissions from area sources versus percent of contained area for each criteria pollutant were produced from these listings and are presented as Figures 20-24.

An examination of the graphs shows that, while the apportioning algorithms are different for different pollutants (the graphs are not identical), they are roughly equivalent in overall distribution of emissions. For example, all five pollutants have 80% of total emissions coming from between six and eight percent of the total AQCR area, and all plots are very similar in overall shape. How much difference really exists, however, would have to be determined by a more detailed analysis, such as a cross correlation of grid square number versus rank-ordered cumulative percent emissions or rank-ordered fractional emission density.

One can combine area and point source emissions for each criteria pollutant within each grid square, using the grid and apportioned emissions outputs from the CAASE system and NEDS point source data. These were produced as rank-ordered listings of emission density (emissions/sq. km) per grid square for each of the criteria pollutants, and associated total emissions for each grid square. A plotter display was also produced of the grid showing emission density for each grid square on a scale of 1-5; plotter displays of the gridded area were produced for each criteria pollutant separately. The plotter displays for each criteria pollutant are presented as Figures 25 to 29.

One can produce a listing of each grid square's emissions by criteria pollutant in descending order by emission density within the grid square, and a listing of point source location by point source number and grid square number, and a list of transferred point sources (if any). "Transferred point sources" refers to those point sources for which UTM coordinates have been recalculated when the gridded area spans more than one UTM zone. Examples are shown as Figures 30-32, respectively, using data from AQCR 070.

SUMMARY

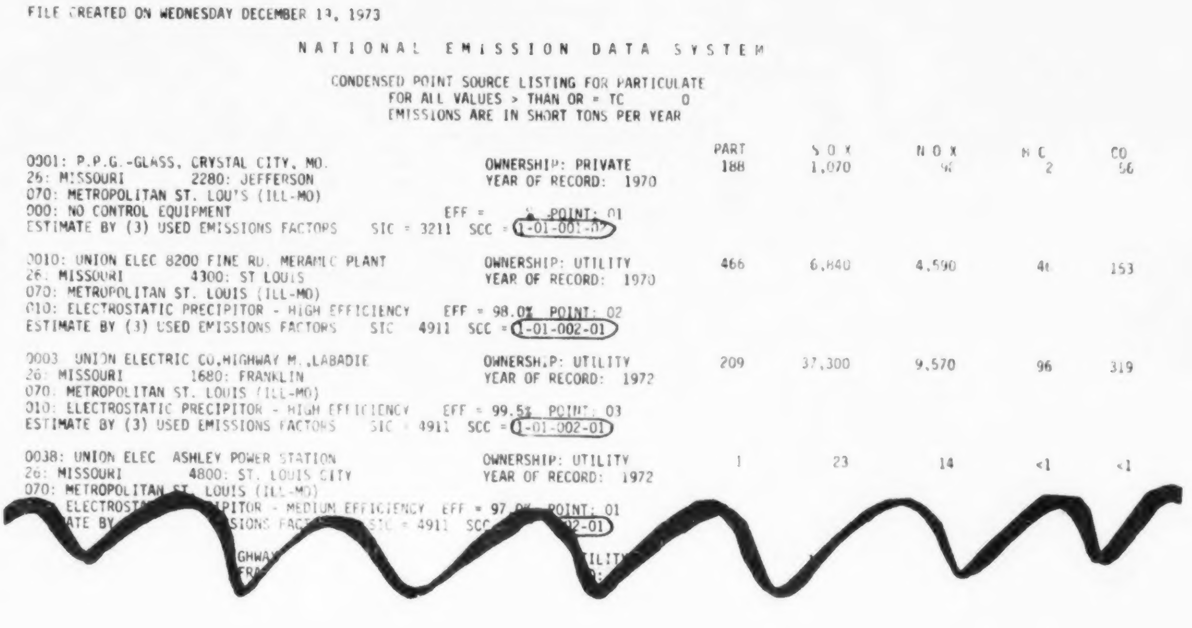
In order to adequately and timely serve the requirements of the Environmental Protection Agency, the National Emissions Data System has been created by the National Air Data Branch. The more than 75,000 point source entries and roughly 3,200 area source entries are stored in NEDS, which is maintained and retrieved by NADB. This includes a growing system of user-oriented retrieval packages.

Retrieval packages include the standard format point and area source listings, abbreviated point-source listings, summary totals and sub-totals at Levels I, II, and III of the SCC code for point sources and corresponding area source sub-totals, and the Weighted Statistical Analysis.

Graphical presentations of retrieved data, which permit rapid and sometimes novel analyses of the characteristics of large amounts of data such as in NEDS, are often useful. The presentation here includes number of point sources versus annual emissions and cumulative percent of annual emissions versus number of sources, both produced from the abbreviated point source listings sorted in descending order by annual emissions; the emission density plots for area source emissions produced from area source grids; and the cumulative percent of emissions from area sources versus percent of contained area in which the emissions occur.

APPENDIX

(ALL FIGURES)



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FILE CREATED ON WEDNESDAY DECEMBER 19, 1973

                        N A T I O N A L   E M I S S I O N   D A T A   S Y S T E M

                              CONDENSED POINT SOURCE LISTING FOR PARTICULATE
                                  FOR ALL VALUES > THAN OR = TC        0
                                  EMISSIONS ARE IN SHORT TONS PER YEAR

                                                                              PART      S O X      N O X      H C      CO
0001: P.P.G.-GLASS, CRYSTAL CITY, MO.              OWNERSHIP: PRIVATE         188      1,070         96        2      56
26: MISSOURI          2280: JEFFERSON              YEAR OF RECORD:  1970
070: METROPOLITAN ST. LOUIS (ILL-MO)
000: NO CONTROL EQUIPMENT                     EFF =      %  POINT: 01
ESTIMATE BY (3) USED EMISSIONS FACTORS    SIC = 3211  SCC = 1-01-001-02

0010: UNION ELEC 8200 FINE RD. MERAMEC PLANT       OWNERSHIP: UTILITY         466      6,840      4,590       46     153
26: MISSOURI          4300: ST LOUIS               YEAR OF RECORD:  1970
070: METROPOLITAN ST. LOUIS (ILL-MO)
010: ELECTROSTATIC PRECIPITOR - HIGH EFFICIENCY    EFF = 98.0%  POINT: 02
ESTIMATE BY (3) USED EMISSIONS FACTORS    SIC   4911  SCC = 1-01-002-01

0003  UNION ELECTRIC CO.HIGHWAY M.,LABADIE         OWNERSHIP: UTILITY         209     37,300      9,570       96     319
26: MISSOURI          1680: FRANKLIN               YEAR OF RECORD:  1972
070: METROPOLITAN ST. LOUIS (ILL-MO)
010: ELECTROSTATIC PRECIPITOR - HIGH EFFICIENCY    EFF = 99.5%  POINT: 03
ESTIMATE BY (3) USED EMISSIONS FACTORS    SIC = 4911  SCC = 1-01-002-01

0038: UNION ELEC  ASHLEY POWER STATION             OWNERSHIP: UTILITY           1         23         14       <1      <1
26: MISSOURI          4800: ST. LOUIS CITY         YEAR OF RECORD:  1972
070: METROPOLITAN ST. LOUIS (ILL-MO)
    ELECTROST       PITOR - MEDIUM EFFICIENCY  EFF = 97.0%  POINT: 01
   ATE BY          SIONS FACT     SIC = 4911  SCC       02-01

                   GHWA                                 ILIT
                   FRA                                  :
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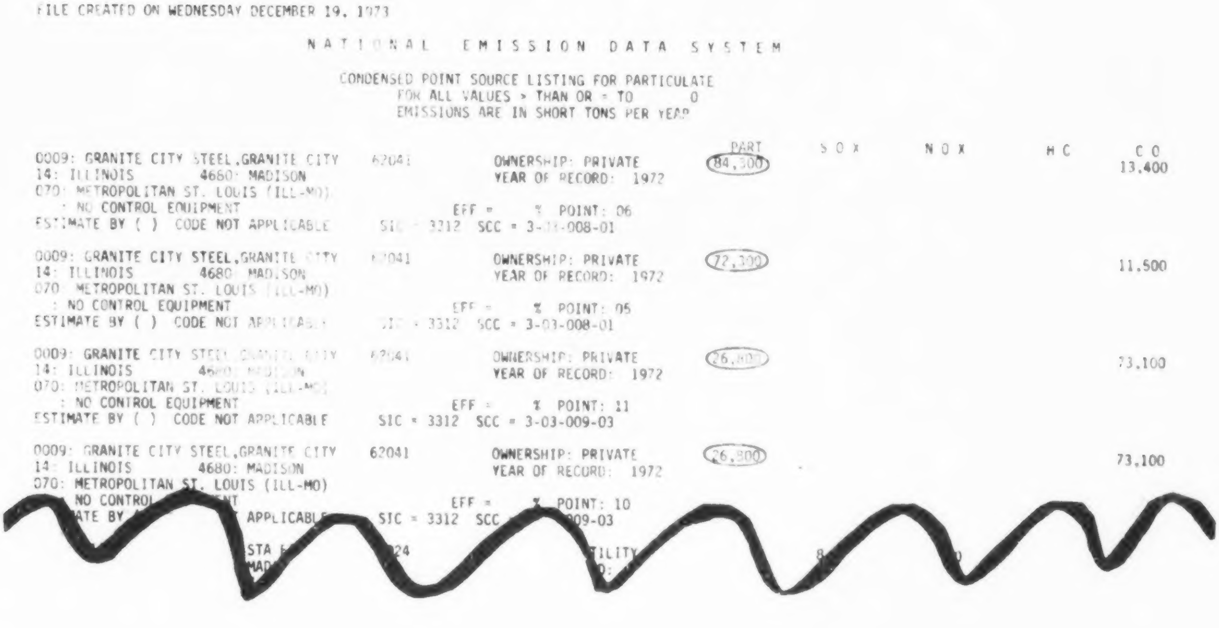
Figure 1. Condensed Point Source Listing Sorted by Source Classification Code (SCC)



```
FILE CREATED ON WEDNESDAY DECEMBER 19, 1973

                        N A T I O N A L   E M I S S I O N   D A T A   S Y S T E M

                              CONDENSED POINT SOURCE LISTING FOR PARTICULATE
                                  FOR ALL VALUES > THAN OR = TO        0
                                  EMISSIONS ARE IN SHORT TONS PER YEAR

                                                                              PART      S O X      N O X      H C      C O
0009: GRANITE CITY STEEL,GRANITE CITY    62041     OWNERSHIP: PRIVATE      84,300                                   13,400
14: ILLINOIS          4680: MADISON                YEAR OF RECORD:  1972
070: METROPOLITAN ST. LOUIS (ILL-MO)
   : NO CONTROL EQUIPMENT                     EFF =      %  POINT: 06
ESTIMATE BY ( )  CODE NOT APPLICABLE      SIC = 3312  SCC = 3-03-008-01

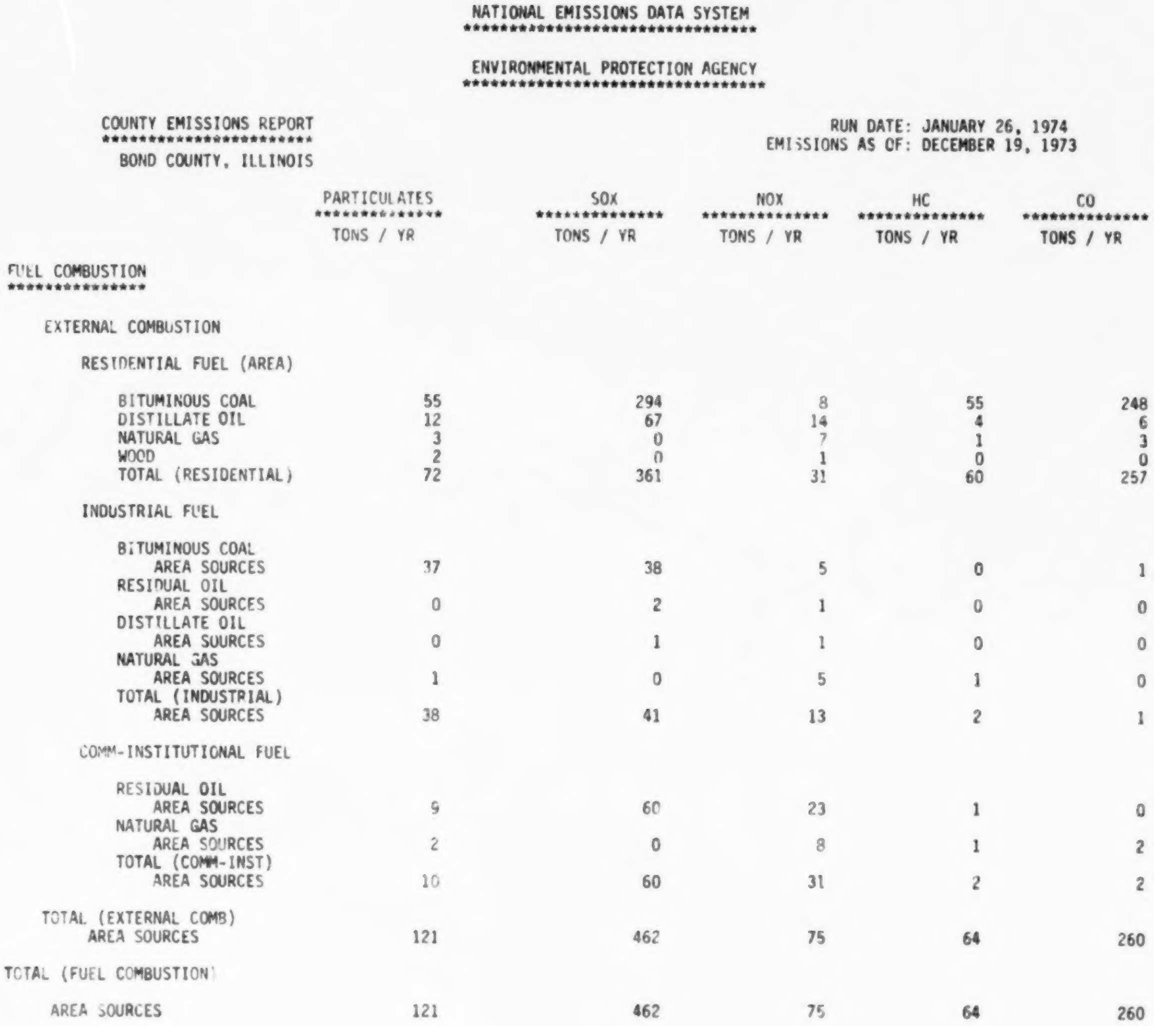
0009: GRANITE CITY STEEL,GRANITE CITY    62041     OWNERSHIP: PRIVATE      72,300                                   11,500
14: ILLINOIS          4680: MADISON                YEAR OF RECORD:  1972
070: METROPOLITAN ST. LOUIS (ILL-MO)
   : NO CONTROL EQUIPMENT                     EFF =      %  POINT: 05
ESTIMATE BY ( )  CODE NOT APPLICABLE      SIC = 3312  SCC = 3-03-008-01

0009: GRANITE CITY STEEL,GRANITE CITY    62041     OWNERSHIP: PRIVATE      26,800                                   73,100
14: ILLINOIS          4680: MADISON                YEAR OF RECORD:  1972
070: METROPOLITAN ST. LOUIS (ILL-MO)
   : NO CONTROL EQUIPMENT                     EFF =      %  POINT: 11
ESTIMATE BY ( )  CODE NOT APPLICABLE      SIC = 3312  SCC = 3-03-009-03

0009: GRANITE CITY STEEL,GRANITE CITY    62041     OWNERSHIP: PRIVATE      26,800                                   73,100
14: ILLINOIS          4680: MADISON                YEAR OF RECORD:  1972
070: METROPOLITAN ST. LOUIS (ILL-MO)
   : NO CONTROL     NT                        EFF =      %  POINT: 10
   ATE BY          APPLICABL      SIC = 3312  SCC       009-03

                   STA         24                       ILITY               8          0
                   MAD                                  D:
```

Figure 2. Condensed Point Source Listing Sorted by Particulate Emission Values



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                                    NATIONAL EMISSIONS DATA SYSTEM
                                    ******************************

                                    ENVIRONMENTAL PROTECTION AGENCY
                                    *******************************

         COUNTY EMISSIONS REPORT                                      RUN DATE: JANUARY 26, 1974
         ***********************                              EMISSIONS AS OF: DECEMBER 19, 1973
           BOND COUNTY, ILLINOIS

                                  PARTICULATES           SOX           NOX            HC             CO
                                  ************     ************  ************  ************   ************
                                   TONS / YR        TONS / YR     TONS / YR     TONS / YR      TONS / YR

FUEL COMBUSTION
***************

    EXTERNAL COMBUSTION

        RESIDENTIAL FUEL (AREA)

            BITUMINOUS COAL              55              294             8            55            248
            DISTILLATE OIL               12               67            14             4              6
            NATURAL GAS                   3                0             7             1              3
            WOOD                          2                0             1             0              0
            TOTAL (RESIDENTIAL)          72              361            31            60            257

        INDUSTRIAL FUEL

            BITUMINOUS COAL
                AREA SOURCES             37               38             5             0              1
            RESIDUAL OIL
                AREA SOURCES              0                2             1             0              0
            DISTILLATE OIL
                AREA SOURCES              0                1             1             0              0
            NATURAL GAS
                AREA SOURCES              1                0             5             1              0
            TOTAL (INDUSTRIAL)
                AREA SOURCES             38               41            13             2              1

        COMM-INSTITUTIONAL FUEL

            RESIDUAL OIL
                AREA SOURCES              9               60            23             1              0
            NATURAL GAS
                AREA SOURCES              2                0             8             1              2
            TOTAL (COMM-INST)
                AREA SOURCES             10               60            31             2              2

    TOTAL (EXTERNAL COMB)
         AREA SOURCES                   121              462            75            64            260

TOTAL (FUEL COMBUSTION)

    AREA SOURCES                        121              462            75            64            260
```

Figure 3. County Emissions Report

```
SOLID WASTE DISPOSAL
********************

  RESIDENTIAL (AREA)

    ON SITE INCINERATION              51          1        2       170       511
    OPEN BURNING                      21          1        8        44       110
    TOTAL (RESIDENTIAL)               72          2       10       215       622

  COMMERCIAL-INSTITUTIONAL

    ON SITE INCINERATION
        AREA SOURCES                   7          1        1         5        11
    OPEN BURNING
        AREA SOURCES                   7          0        3        15        38
    TOTAL (COMM-INST)
        AREA SOURCES                  14          1        4        21        49

  INDUSTRIAL

    ON SITE INCINERATION
        AREA SOURCES                  32          4        5        27        54
    OPEN BURNING
        AREA SOURCES                   9          1        3        19        47
    TOTAL (INDUSTRIAL)
        AREA SOURCES                  41          5        9        46       101

  TOTAL (SOLID WASTE DISP)

    AREA SOURCES                     127          8       22       281       772

TRANSPORTATION (AREA)
*********************

  LAND VEHICLES

    GASOLINE

      LIGHT VEHICLES                  42         25      605      1211      6137
      HEAVY VEHICLES                   5          3      165       310      1222
      OFF HIGHWAY                      5          3      106       335      1833
      TOTAL (GASOLINE)                52         31      877      1855      9193

    DIESEL

      HEAVY VEHICLES                   7         14      198        20       117
      OFF HIGHWAY                      0          1        9         1         6
      RAIL                             1          2        3         2         2
      TOTAL (DIESEL)                   8         17      210        23       125

  GAS HANDLING EVAP LOSS               0          0        0       134         0

  TOTAL (TRANSPORTATION)              60         48     1087      2012      9318

MISCELLANEOUS (AREA)
********************

  SOLVENT EVAPORATION LOSS             0          0        0        40         0
  TOTAL (MISCELLANEOUS)                0          0        0        40         0

GRAND TOTAL
***********

  AREA SOURCES                       308        518     1184      2397     10350
  TOTAL                              308        518     1184      2397     10350
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Figure 3. (Continued)

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                                          NATIONAL EMISSIONS DATA SYSTEM
                                          ******************************

                                          ENVIRONMENTAL PROTECTION AGENCY
                                          *******************************

            AQCR EMISSIONS REPORT                                                     RUN DATE: JANUARY 26, 1974
            *********************                                          EMISSIONS AS OF: DECEMBER 19, 1973
              AQCR 070 METROPOLITAN ST. LOUIS (ILL-MO)

                                     PARTICULATES         SOX               NOX               HC                CO
                                     **************  **************   **************   **************   **************
                                      TONS / YR        TONS / YR         TONS / YR        TONS / YR        TONS / YR
FUEL COMBUSTION
***************

   EXTERNAL COMBUSTION

      RESIDENTIAL FUEL (AREA)

         BITUMINOUS COAL                  2147           11424              322             2147             9663
         DISTILLATE OIL                    544            2358              652              163              277
         NATURAL GAS                       813              26             2140              342              856
         WOOD                              157               3               63               13               13
         TOTAL (RESIDENTIAL)              3662           13810             3178             2665            10803

      ELEC GENERATION (POINT)

         ANTHRACITE COAL                   188            1069               98                2               56
         BITUMINOUS COAL                 46766          933254           270602             2199             7304
         RESIDUAL OIL                      100            4939             1363               26               39
         DISTILLATE OIL                     50             102              699               13               20
         NATURAL GAS                       139              10            10732               18              304
         TOTAL (ELEC GEN)                47243          939375           283495             2258             7724

      INDUSTRIAL FUEL

         BITUMINOUS COAL
            AREA SOURCES                 15522           14342             2022              135              270
            POINT SOURCES                15147           40190             5519              227              510
         RESIDUAL OIL
            AREA SOURCES                   117            1062              305               15                1
            POINT SOURCES                  952           17194             3887              194              247
         DISTILLATE OIL
            AREA SOURCES                   125             316              498               25                2
            POINT SOURCES                  107             200              429               <1               29
         NATURAL GAS
            AREA SOURCES                   533              18             5333             1185               12
            POINT SOURCES                  131               6             2287               30              160
         PROCESS GAS
            POINT SOURCES                    0               0               67                1                5
         WOOD
            POINT SOURCES                    8               0                3                1                1
         TOTAL (INDUSTRIAL)
            AREA SOURCES                 16257           15738             9159             1360              284
            POINT SOURCES                16344           57590            12191              478              951

      COMM-INSTITUTIONAL FUEL

         BITUMINOUS COAL
            AREA SOURCES                  3053            5958              515              112              403
            POINT SOURCES                 1271            1683              229               16               33
         RESIDUAL OIL
            AREA SOURCES                   410            2839             1069               53                4
            POINT SOURCES                   44             392              115                6                8
         DISTILLATE OIL
            AREA SOURCES                   277             524             1108               55                4
            POINT SOURCES                    6              13               24                1                2
         NATURAL GAS
            AREA SOURCES                   299               9             1572              126              314
            POINT SOURCES                   35               1              312               15               38
         LIQUID PETROL GAS
            POINT SOURCES                    0               1                1                0                0
         TOTAL (COMM-INST)
            AREA SOURCES                  4039            9331             4265              347              725
            POINT SOURCES                 1356            2090              681               36               80
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Figure 4. AQCR Emissions Report

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      TOTAL (EXTERNAL COMB)
                AREA SOURCES                    23997          38879          15602           4372          11812
                POINT SOURCES                   64942         999056         296367           2770           8755

   INTERNAL COMBUSTION (POINT)

      ELECTRIC GENERATION

         DISTILLATE OIL                             6             16            410            147             32
         NATURAL GAS                                2              1            247            144             24
         DIESEL                                     0              0              7              1              4
         TOTAL (ELEC GEN)                           9             18            663            293             60

      INDUSTRIAL FUEL

         NATURAL GAS                                0              0             29              0              0
         TOTAL (INDUSTRIAL)                         0              0             29              0              0

      TOTAL (INTERNAL COMB)                         9             18            692            293             60

   TOTAL (FUEL COMBUSTION)

      AREA SOURCES                              23997          38879          15602           4372          11812
      POINT SOURCES                             64951         999074         297059           3063           8815

INDUSTRIAL PROCESS (POINT)
**************************

   CHEMICAL MANUFACTURING                         381           8605            139           2193          35097
   FOOD/AGRICULTURAL                             1433              0              0              0              0
   PRIMARY METAL                               213175         137595             73           1578        2644503
   SECONDARY METALS                               371           1894             34             16           1191
   MINERAL PRODUCTS                             30262              0           1324            535              0
   PETROLEUM INDUSTRY                            5876          38025          11951          12561         141199
   WOOD PRODUCTS                                    7              0              0              0              0
   EVAPORATION                                      2              0              0          58238              0
   METAL FABRICATION                               26              0              0              0              0
   INPROCESS FUEL                                 110           1705             84             15             17
   OTHER/NOT CLASSIFIED                             1              0              0              0              0

   TOTAL (INDUSTRIAL)                          251638         187825          13604          75137        2822007

SOLID WASTE DISPOSAL
********************

   GOVERNMENT (POINT)

      MUNICIPAL INCINERATION                      514            365            292            219           5112
      TOTAL (GOVERNMENT)                          514            365            292            219           5112

   RESIDENTIAL (AREA)

      ON SITE INCINERATION                       1088             18             36           3626          10878
      OPEN BURNING                                682             43            256           1450           3625
      TOTAL (RESIDENTIAL)                        1770             61            292           5076          14503

   COMMERCIAL-INSTITUTIONAL

      ON SITE INCINERATION
         AREA SOURCES                             144             18             24            120            240
         POINT SOURCES                              4              1              0              4              5
      OPEN BURNING
         AREA SOURCES                             226             14             85            479           1198
      TOTAL (COMM-INST)
         AREA SOURCES                             370             32            109            599           1438
         POINT SOURCES                              4              1              0              4              5

   INDUSTRIAL

      ON SITE INCINERATION
         AREA SOURCES                            1434            179            239           1195           2390
         POINT SOURCES                             32             29             37             55            330
      OPEN BURNING
         AREA SOURCES                            1014             63            380           2156           5389
      TOTAL (INDUSTRIAL)
         AREA SOURCES                            2448            243            619           3351           7779
         POINT SOURCES                             32             29             37             55            330
```

Figure 4 (continued). AQCR Emissions Report.

```
TOTAL (SOLID WASTE DISP)

      AREA SOURCES                 4588         336        1070         9026       23721
      POINT SOURCES                 550         395   [illegible]        278        5446

TRANSPORTATION (AREA)
*********************

   LAND VEHICLES

     GASOLINE

       LIGHT VEHICLES              4455        2673       63860       141913      803634
       HEAVY VEHICLES               419         251       13972        30167      127582
       OFF HIGHWAY                   65          40        1419         4459       24432
       TOTAL (GASOLINE)            4939        2965       79251       176540      955646

     DIESEL

       HEAVY VEHICLES               652        1304       18475         1848       10868
       OFF HIGHWAY                  130         271        3711          371        2257
       RAIL                         729        1895        2187         1458        2041
       TOTAL (DIESEL)              1511        3470       24373         3676       15165

   AIRCRAFT

     MILITARY                      1158         221         556         2695        2893
     CIVIL                           41           8          37          182        1042
     COMMERCIAL                     906         201         567         2174        5156
     TOTAL (AIRCRAFT)              2105         430        1160         5051        9090

   VESSELS

     DIESEL FUEL                    371         966        1114          743        1040
     RESIDUAL OIL                    13          56          34            2           0
     TOTAL (VESSELS)                384        1022        1148          744        1040

   GAS HANDLING EVAP LOSS             0           0           0        12052           0

   TOTAL (TRANSPORTATION)          8940        7887      105932       198063      980944

MISCELLANEOUS (AREA)
********************

   SOLVENT EVAPORATION LOSS           0           0           0         5184           0
   TOTAL (MISCELLANEOUS)              0           0           0         5184           0

GRAND TOTAL
***********

   AREA SOURCES                   37525       47101      122554       216646     1016477
   POINT SOURCES                 317140     1187294      310992        78477     2836269
   TOTAL                         354665     1234395      433547       295123     3852746
```

Figure 4 (continued). AQCR Emissions Report.

Figure 4. (Continued)

```
                                  ***STATIONARY SOURCE FUEL SUMMARY REPORT***

                                        NATIONAL EMISSION DATA SYSTEM
                                        ************* ***************

                                       ENVIRONMENTAL PROTECTION AGENCY
                                       *******************************

                                                                                          USER FILE CREATE DATE
                                                                                      WEDNESDAY DECEMBER 19, 1973
COUNTY FUEL REPORT ILLINOIS              COUNTY: BOND
                                                                                              DATE OF RUN
                                                                                               01/26/74

                                             CURRENT ANNUAL FUEL SUMMARY
                                             ********* ************* ** *

                  ANTH COAL      BITM COAL      RESID OIL      DIST OIL       NAT GAS        PROC GAS       COKE          WOOD
                ************   ************   ************   ************   ************   ************   ************   ************
                    TONS           TONS       1000 GALS      1000 GALS      10E6 CUFT      10E6 CUFT        TONS           TONS
AREA SOURCES
  RESIDENTIAL                      5520                          2350           290                                          200
  INDUSTRIAL                        710             20             40            60
  COMM-INSTL                                       760                          170
         TOTAL                     6230            790           2390           520                                          200
POINT SOURCES
  EXT COMB
      ELEC GEN
      INDUSTRIAL
      COMM-INSTL
         TOTAL

  INPROCESS

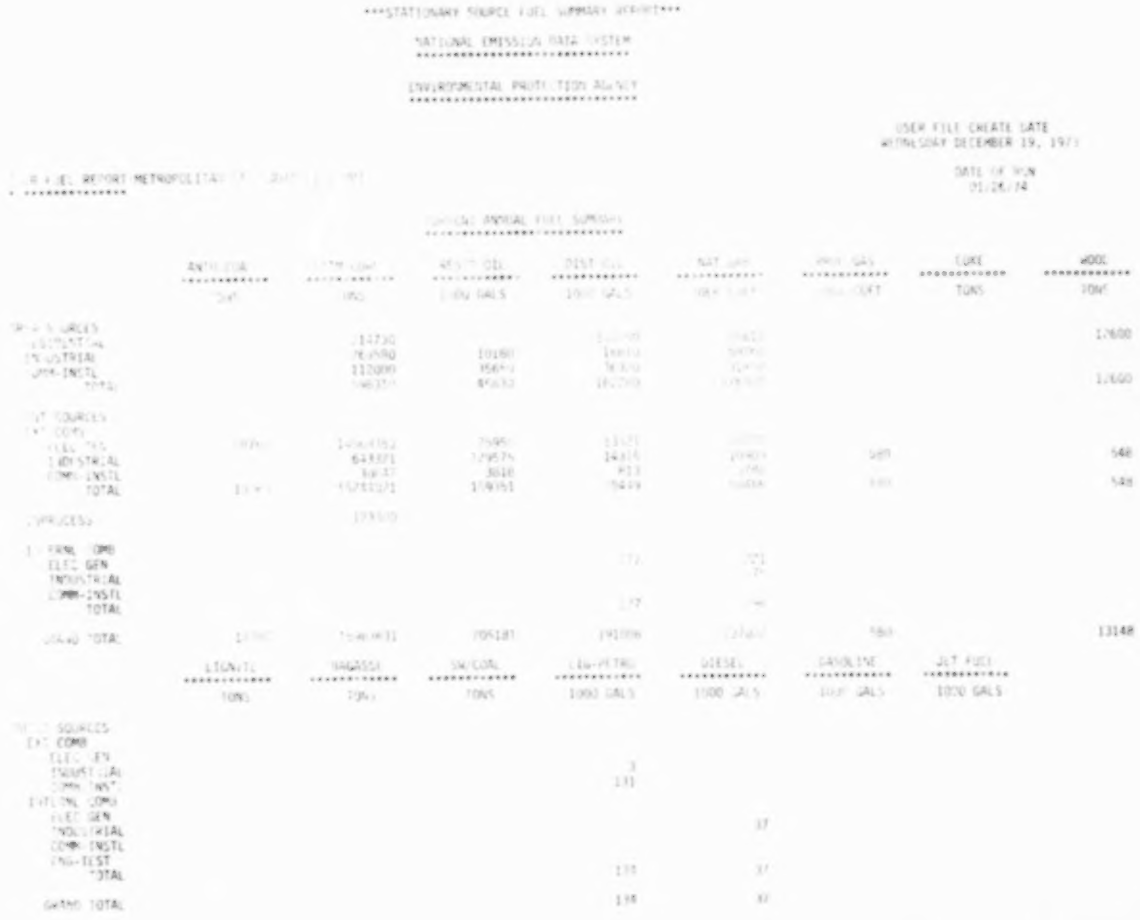
  INTERNL COMB
      ELEC GEN
      INDUSTRIAL
      COMM-INSTL
         TOTAL

  GRAND TOTAL                      6230            790           2390           520                                          200
                  LIGNITE        BAGASSE        SW/COAL        LIQ-PETRO      DIESEL         GASOLINE       JET FUEL
                ************   ************   ************   ************   ************   ************   ************
                    TONS           TONS           TONS       1000 GALS      1000 GALS      1000 GALS      1000 GALS

POINT SOURCES
  EXT COMB
      ELEC GEN
      INDUSTRIAL
      COMM-INSTL
  INTERNL COMB
      ELEC GEN
      INDUSTRIAL
      COMM-INSTL
      ENG-TEST
         TOTAL

     GRAND TOTAL
```

Figure 5. County Fuel Report



```
                         ***STATIONARY SOURCE FUEL SUMMARY REPORT***

                              NATIONAL EMISSION DATA SYSTEM
                              *****************************

                              ENVIRONMENTAL PROTECTION AGENCY
                              *******************************

                                                                              USER FILE CREATE DATE
                                                                         WEDNESDAY DECEMBER 19, 1973

AQCR FUEL REPORT METROPOLITAN [illegible]                                          DATE OF RUN
* **************                                                                     01/26/74

                              CURRENT ANNUAL FUEL SUMMARY
                              ***************************

              ANTH COAL    BITUM COAL    RESID OIL    DIST OIL     NAT GAS     PROC GAS      COKE        WOOD
            ************ ************ ************ ************ ************ ************ ************ ************
                TONS         TONS       1000 GALS    1000 GALS    MILL CUFT    MILL CUFT      TONS        TONS

AREA SOURCES
  RESIDENTIAL                214730                 [illegible]  [illegible]                               12600
  INDUSTRIAL                 769590       10180      [illegible]  [illegible]
  COMM-INSTL                 112000       35652      [illegible]  [illegible]
         TOTAL              1096320       45832        162380     [illegible]                              12600

POINT SOURCES
  EXT COMB
    ELEC GEN    [illegible] 14564352      25958         13121     [illegible]
    INDUSTRIAL                643371     129575         14416        20907          580                     548
    COMM-INSTL                 38437       3818           813         1790
         TOTAL  [illegible] 15733321     159351         28449     [illegible]  [illegible]                 548

  IND PROCESS                 179510

  INTERNL COMB
    ELEC GEN                                              177          221
    INDUSTRIAL                                                          27
    COMM-INSTL
         TOTAL                                            177          248

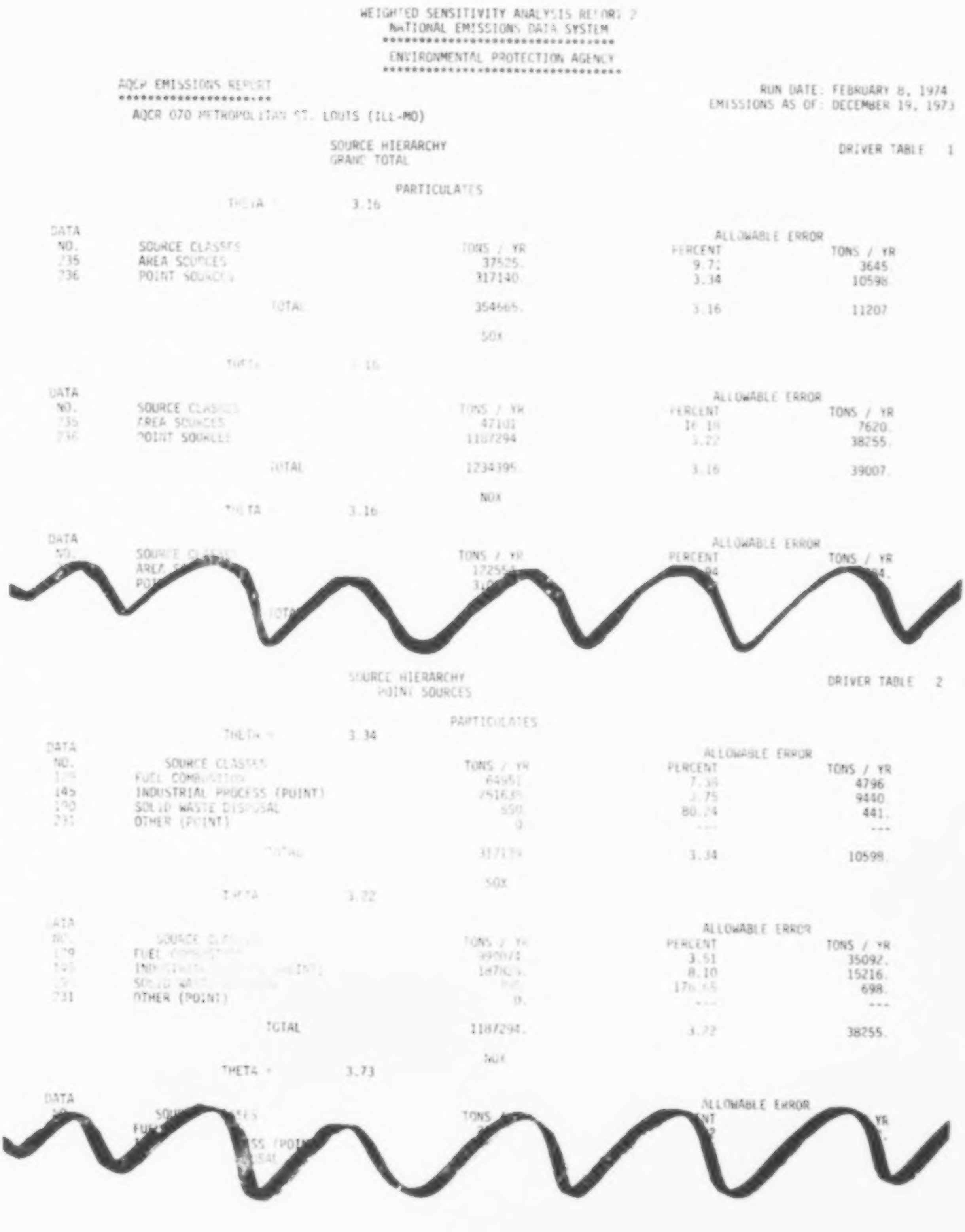
   GRAND TOTAL  [illegible] [illegible]     205183        191006     [illegible]      580                   13148

                 LIGNITE      BAGASSE      SW/COAL     LIQ-PETRO     DIESEL      GASOLINE     JET FUEL
            ************ ************ ************ ************ ************ ************ ************
                  TONS         TONS         TONS      1000 GALS    1000 GALS    1000 GALS    1000 GALS

POINT SOURCES
  EXT COMB
    ELEC GEN
    INDUSTRIAL                                              3
    COMM-INSTL                                            131
  INTERNL COMB
    ELEC GEN
    INDUSTRIAL                                                          37
    COMM-INSTL
    ENG-TEST
         TOTAL                                            134           37

   GRAND TOTAL                                            134           37
```

Figure 6. AQCR Fuel Report



```
                         WEIGHTED SENSITIVITY ANALYSIS REPORT 2
                            NATIONAL EMISSIONS DATA SYSTEM
                           ********************************
                            ENVIRONMENTAL PROTECTION AGENCY
                           ********************************
        AQCR EMISSIONS REPORT
        *********************                                  RUN DATE: FEBRUARY 8, 1974
          AQCR 070 METROPOLITAN ST. LOUIS (ILL-MO)        EMISSIONS AS OF: DECEMBER 19, 1973

                        SOURCE HIERARCHY                                   DRIVER TABLE   1
                        GRAND TOTAL

                                   PARTICULATES
              THETA =          3.16

 DATA                                                         ALLOWABLE ERROR
  NO.       SOURCE CLASSES               TONS / YR         PERCENT           TONS / YR
  235       AREA SOURCES                    37525.            9.71                3645.
  236       POINT SOURCES                  317140.            3.34               10598.

                     TOTAL                 354665.            3.16               11207.

                                   SOX

              THETA =          3.16

 DATA                                                         ALLOWABLE ERROR
  NO.       SOURCE CLASSES               TONS / YR         PERCENT           TONS / YR
  235       AREA SOURCES                    47101.           16.18                7620.
  236       POINT SOURCES                 1187294.            3.22               38255.

                     TOTAL                1234395.            3.16               39007.

                                   NOX
              THETA =          3.16

 DATA                                                         ALLOWABLE ERROR
  NO.       SOURCE CLASSES               TONS / YR         PERCENT           TONS / YR

                        SOURCE HIERARCHY                                   DRIVER TABLE   2
                          POINT SOURCES

                                   PARTICULATES
              THETA =          3.34
 DATA                                                         ALLOWABLE ERROR
  NO.         SOURCE CLASSES             TONS / YR         PERCENT           TONS / YR
  179       FUEL COMBUSTION                 64951.            7.38                4796.
  145       INDUSTRIAL PROCESS (POINT)     251639.            3.75                9440.
  190       SOLID WASTE DISPOSAL              550.           80.24                 441.
  231       OTHER (POINT)                       0.             ---                 ---

                     TOTAL                 317139.            3.34               10598.

                                   SOX
              THETA =          3.72

 DATA                                                         ALLOWABLE ERROR
  NO.         SOURCE CLASSES             TONS / YR         PERCENT           TONS / YR
  179       FUEL COMBUSTION                999074.            3.51               35092.
  145       INDUSTRIAL PROCESS (POINT)     187825.            8.10               15216.
  190       SOLID WASTE DISPOSAL              395.          176.65                 698.
  231       OTHER (POINT)                       0.             ---                 ---

                     TOTAL                1187294.            3.72               38255.

                                   NOX
              THETA =          3.73

 DATA                                                         ALLOWABLE ERROR
```

Figure 7. Weighted Sensitivity Analysis

152

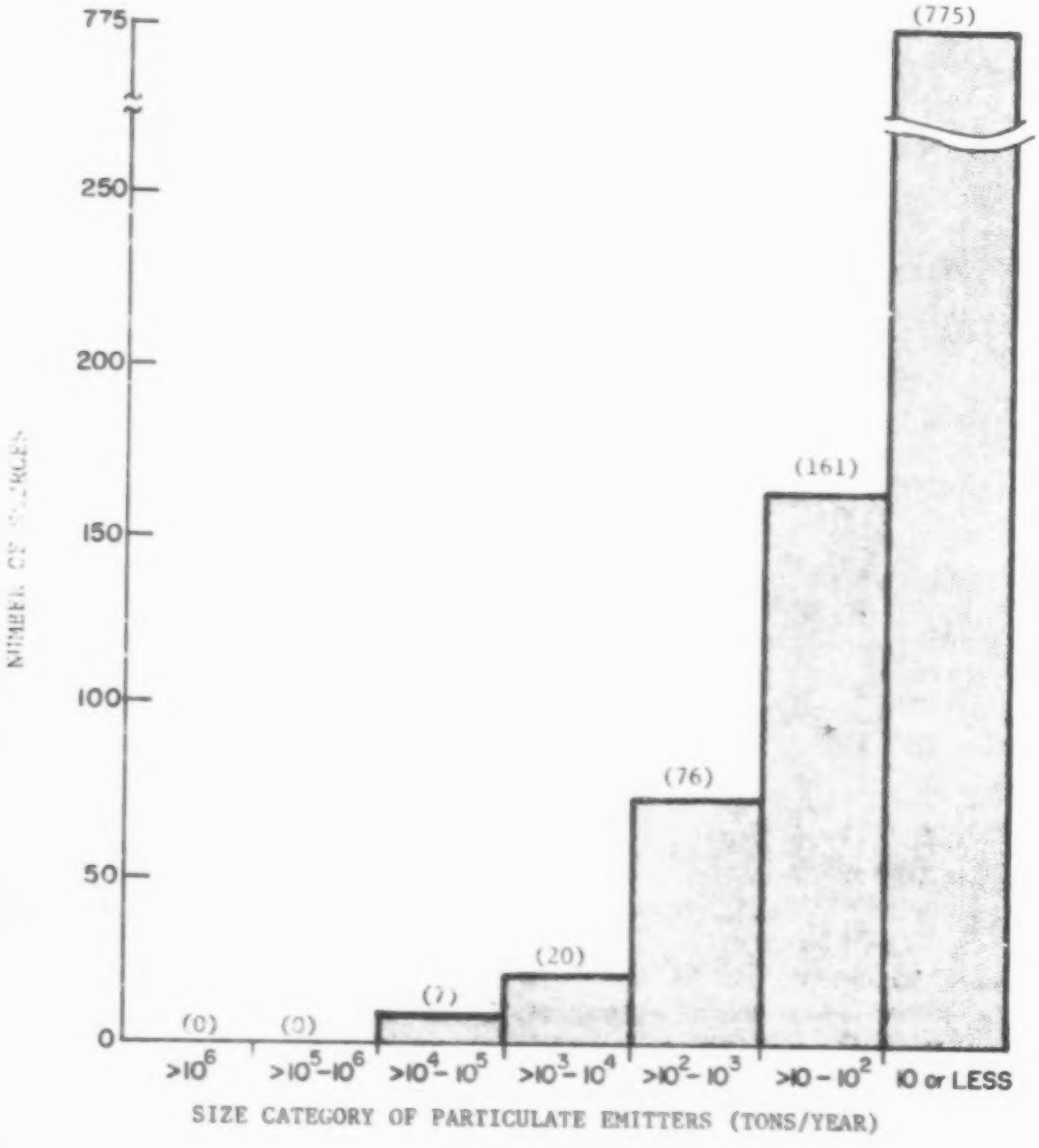


Figure 8. Frequency Distribution of Particulate Emitters by Total Emissions, Metropolitan St. Louis AQCR (070) 1,039 Total Point Sources

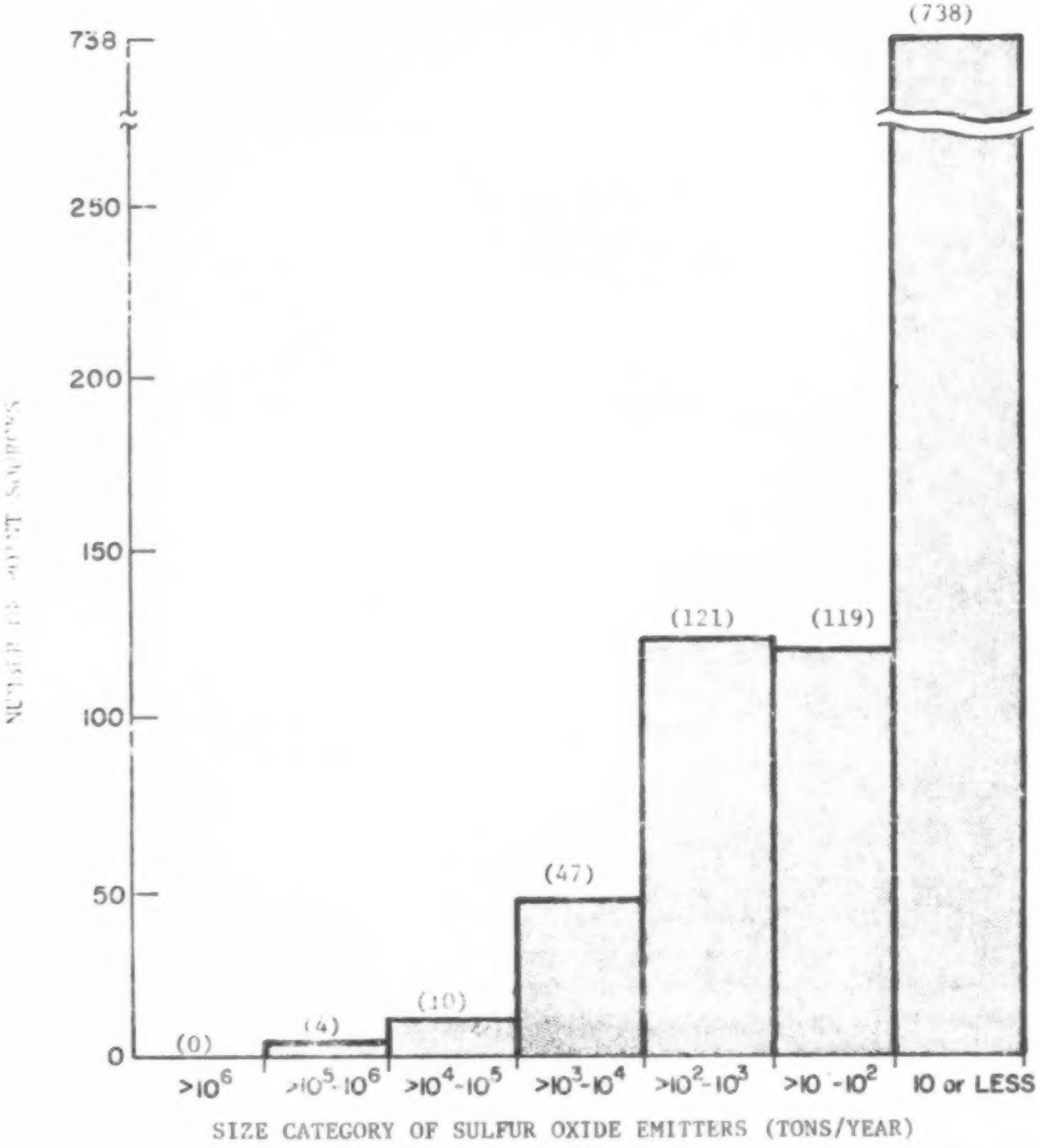


Figure 9. Frequency Distribution of Sulfur Oxide Emitters by Total Emissions, Metropolitan St. Louis AQCR (070) 1,039 Total Point Sources

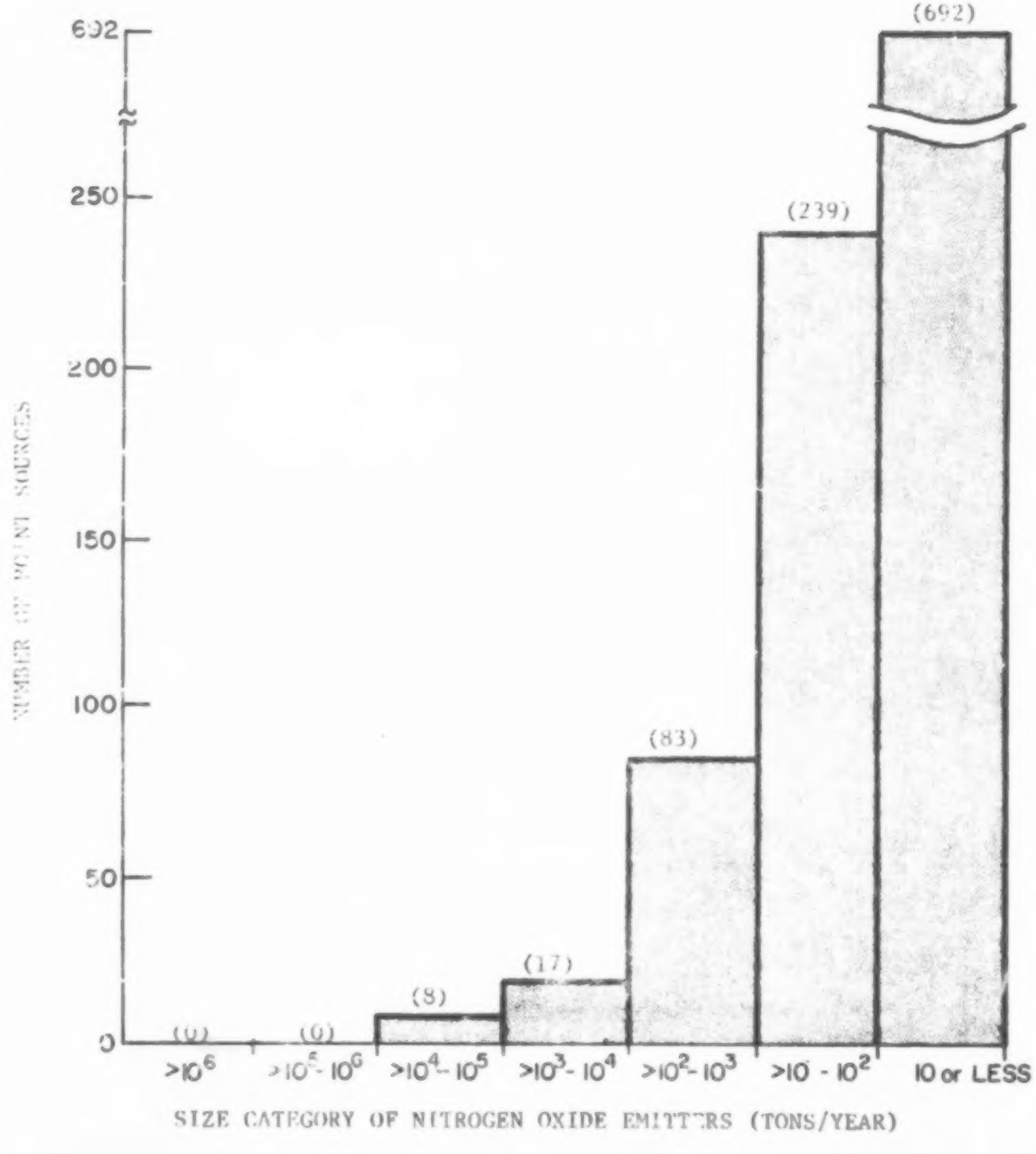


Figure 10. Frequency Distribution of Nitrogen Oxide Emitters by Total Emissions, Metropolitan St. Louis AQCR (070) 1,039 Total Point Sources

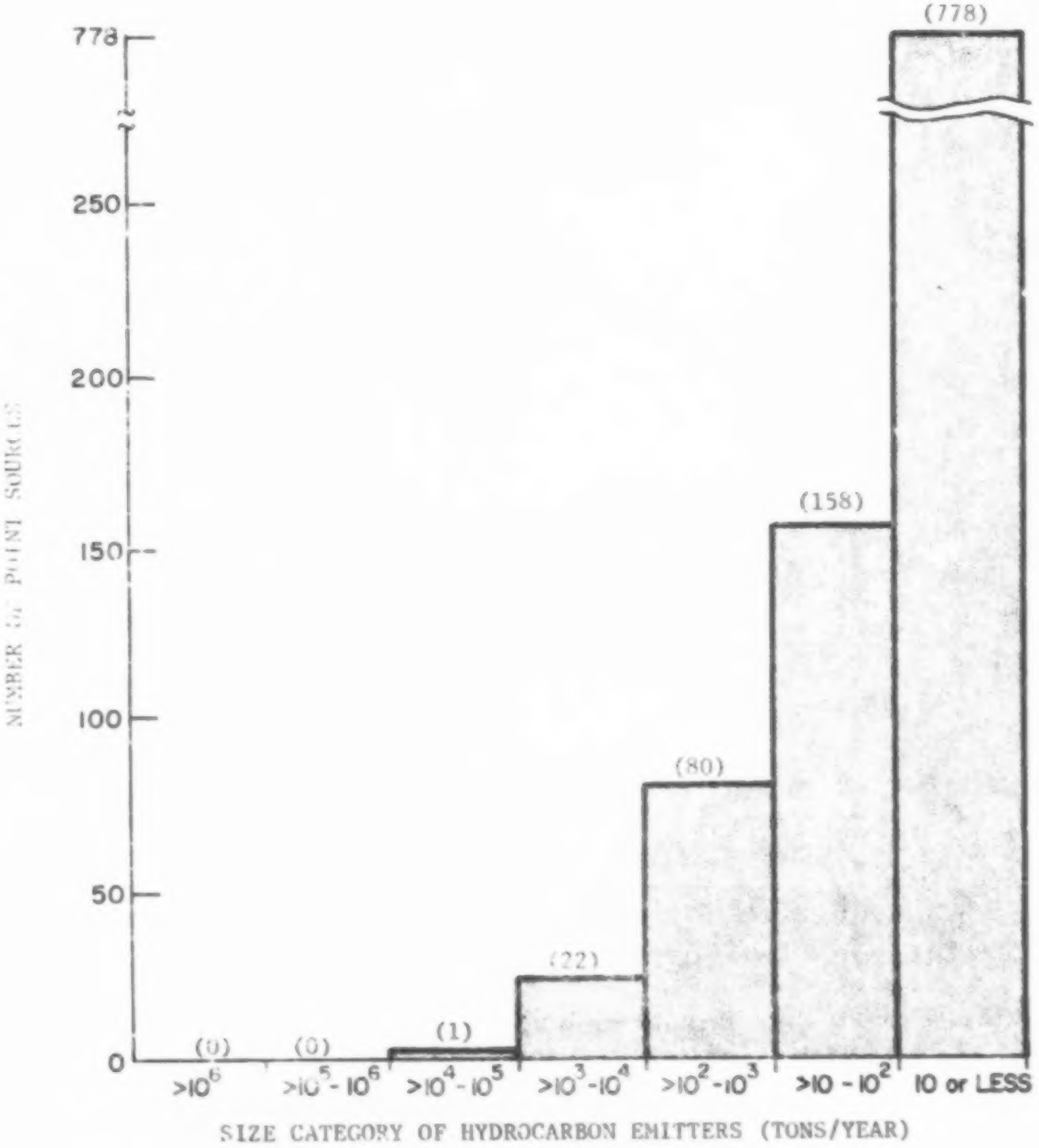


Figure 11. Frequency Distribution of Hydrocarbon Emitters by Total Emissions, Metropolitan St. Louis AQCR (070) 1,039 Total Point Sources

C 156<

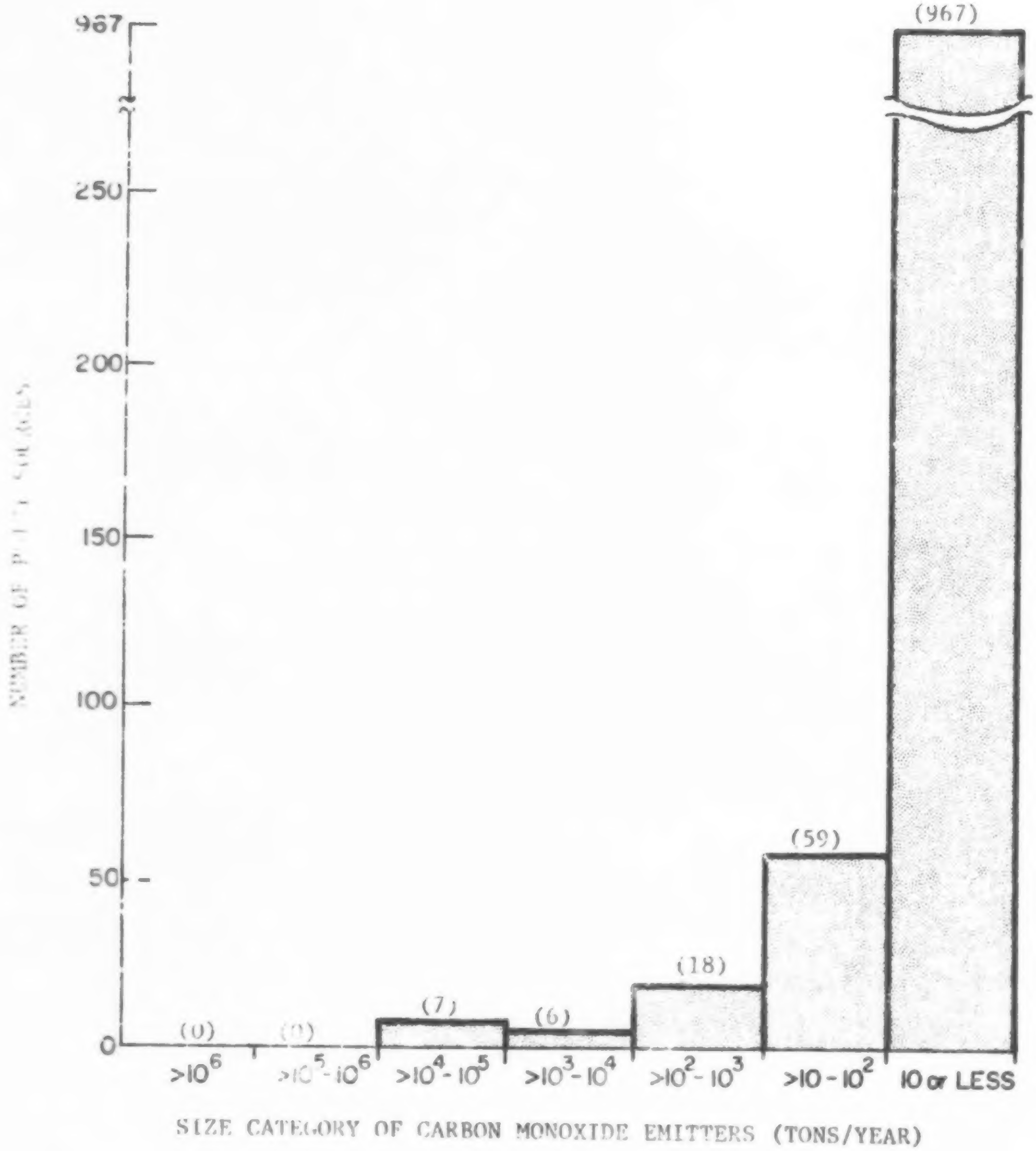


Figure 12. Frequency Distribution of Carbon Monoxide Emitters by Total Emissions, Metropolitan St. Louis AQCR (070) 1,039 Total Point Sources

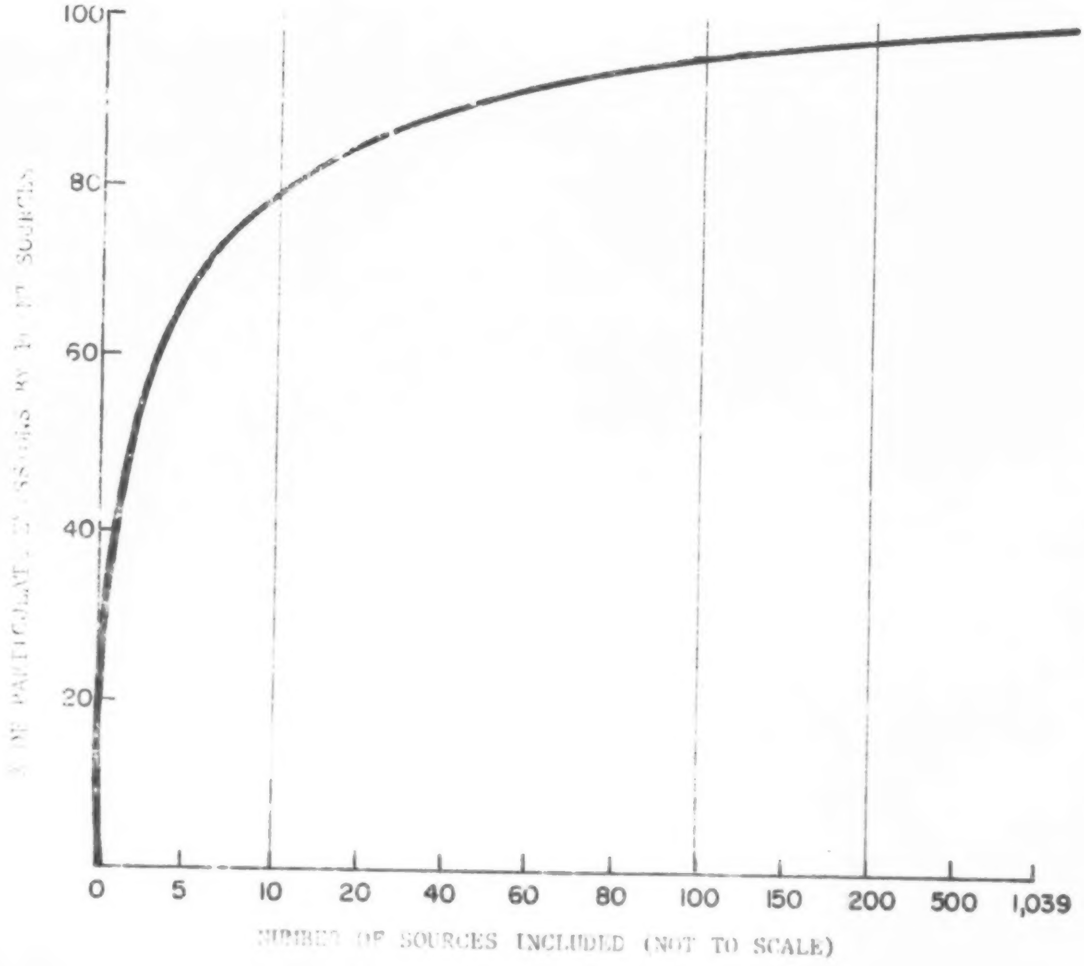


Figure 13. Percent of Particulate Emissions by 1,039 Point Sources, Metropolitan St. Louis AQCR (070), Total Emissions of 322,000 Tons/Year

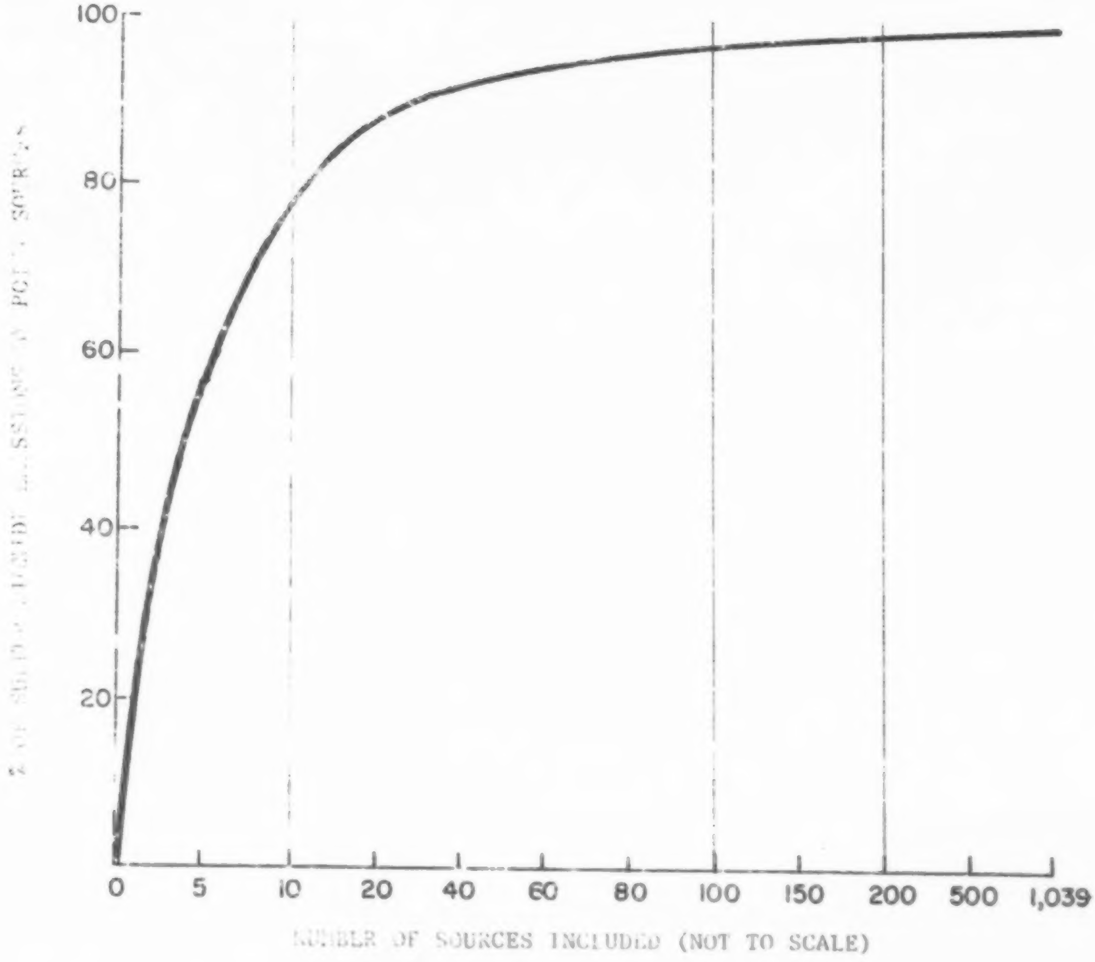


Figure 14. Percent of Sulfur Oxide Emissions by 1,039 Point Sources, Metropolitan St. Louis AQCR (070), Total Emissions of 1,188,000 Tons/Year

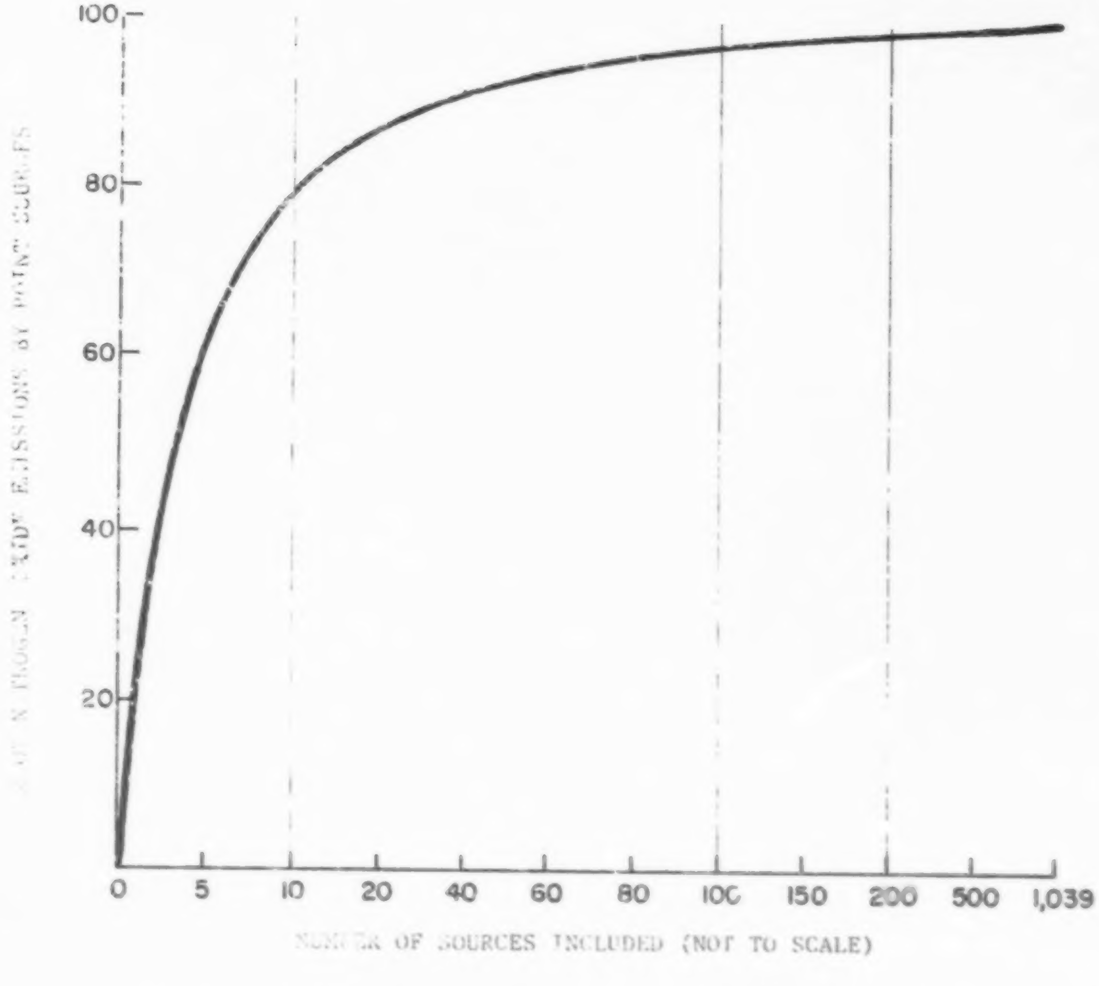


Figure 15. Percent of Nitrogen Oxide Emissions by 1,039 Point Sources, Metropolitan St. Louis AQCR (070), Total Emissions of 312,600 Tons/Year

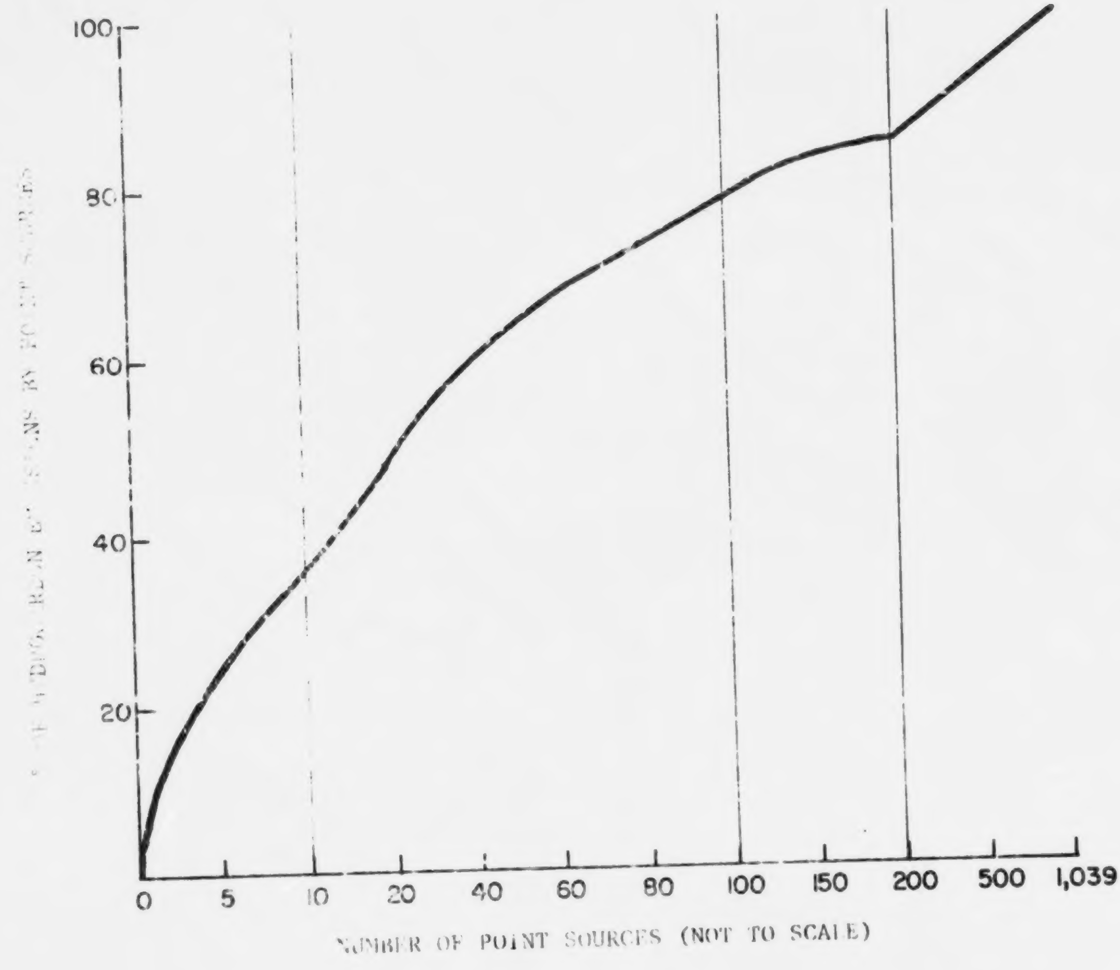


Figure 16. Percent of Hydrocarbon Emissions by 1,039 Point Sources, Metropolitan St. Louis AQCR, Total Emissions of 80,155 Tons/Year

C 161<

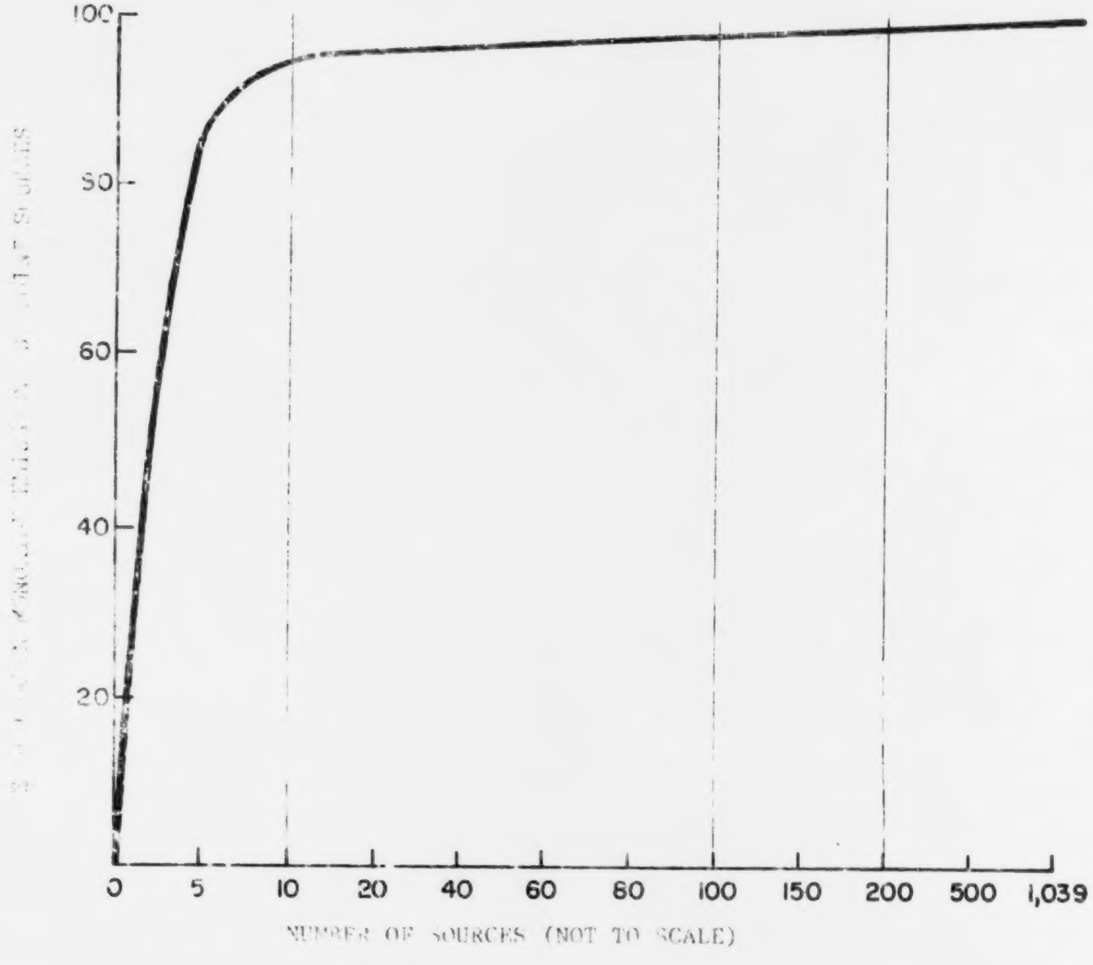


Figure 17. Percent of Carbon Monoxide Emissions by 1,039 Point Sources, Metropolitan St. Louis AQCR (070), Total Emissions of 2,842,000 Tons/Year

```
                                       SOURCE ID: A  STATE- 26  COUNTY- 3280  AQCR- 070  YEAR- 70
-----------------------------------------------------------------------------------------------------------------------------------
|EM-EST-PRT(100-TONS)=        113| EM-EST-SO2(100-TONS)=      245| EM-EST-NOX(100-TONS)=          | EM-EST-HC(100-TONS)=              |
| EM-EST-CO(100-TONS)=           |       % SULF-ANTH-COAL=       |      % SULF-BITUM-COAL=     2.8|      % SULF-DIST-OIL=          0.2|
|     % SULF-RESID-OIL=       1.6|        % ASH-ANTH-COAL=       |       % ASH-BITUM-COAL=     9.4|    RES-ANTH(10-TONS)=             |
|   RES-BITUM(10-TONS)=      1956|RES-DIS-OIL(10E4-GAL)=     1356|RES-RID-OIL(10E4-GAL)=         0|RES-N-GAS(10E7-CUFT)=         2640|
|   RES-WOOD(100-TONS)=        18|       CI-ANTH(10-TONS)=       |       CI-BITUM(10-TONS)=   11200|CI-DIS-OIL(10E4-GAL)=         3500|
|CI-RID-OIL(10E4-GAL)=          0|  CI-N-GAS(10E7-CUFT)=     1110|       CI-WOOD(100-TONS)=      0|    IND-ANTH(10-TONS)=             |
|   IND-BITUM(10-TONS)=     10000|       IND-COKE(10-TONS)=      |IND-DIS-OIL(10E4-GAL)=      1000|IND-RD-OIL(10E4-GAL)=            80|
|IND-N-GAS(10E7-CUFT)=       2860|     IND-WOOD(100-TONS)=      0|IND-PR-GAS(10E7-CUFT)=          |-----------------------------------|
| RES-OS-INC(10-TONS)=          0|  IND-OS-INC(100-TONS)=      0|   CI-OS-INC(100-TONS)=        0|   PART-EMS(T/YR)=     12067.564|
|RES-OP-BRN(100-TONS)=          0|IND-OPN-BRN(100-TONS)=       0|  CI-OPN-BRN(100-TONS)=        0|    SO2-EMS(T/YR)=     14893.097|
|GAS-LT-VEH(1000-GAL)=     261116|GAS-HVY-VEH(1000-GAL)=    35512|GAS-OFF-HWY(1000-GAL)=          |    NOX-EMS(T/YR)=     32897.865|
|DIE-HV-VEH(1000-GAL)=      24148|DIE-OFF-HWY(10E4-GAL)=      604| DIE-RR-LOC(10E4-GAL)=      975|     HC-EMS(T/YR)=     51644.423|
|     COUNTY-POP(1000)=       622|           DENSITY-CODE=      9|MIL-AIRCRAFT(100-LTO)=          |     CO-EMS(T/YR)=    259655.105|
|CIV-AIRCRAFT(10-LTO)=           |COMM-AIRCRAFT(10-LTO)=         |     VES-BITUM(10-TONS)=        | NO. 6-EMS(T/YR)=          0.000|
|VES-DIE-OL(10E4-GAL)=        595|VES-RID-OIL(10E4-GAL)=         |      VES-GAS(1000-GAL)=        | NO. 7-EMS(T/YR)=          0.000|
|  EVAP-SOLVENT(T/YR)=        686|    EVAP-GAS(10E5-GAL)=    2966|VEH-MI-LA-RD(10E4-MI)=          | NO. 8-EMS(T/YR)=          0.000|
|VEH-MI-RURL(10E4-MI)=           |VEH-MI-SUBAN(10E4-MI)=         |VEH-MI-URBAN(10E4-MI)=          | NO. 9-EMS(T/YR)=          0.000|
|DIRT-RD-TRV(1000-MI)=           | DIRT-AIR-STRIPS(LTO)=         |CONST-LAND(1000-ACRE)=          |NO. 10-EMS(T/YR)=          0.000|
|ROCK-H-ST(1000-TONS)=           |FOREST-FIRE-AR(ACRES)=         |FOR-FIRE-QU(TON/ACRE)=          |NO. 11-EMS(T/YR)=          0.000|
|SLASH-BRN-ARE(ACRES)=           |SLASH-BN-QU(TON/ACRE)=         | ORCHARD-HEATERS(100)=          |NO. 12-EMS(T/YR)=          0.000|
|ORCH-DA-FIRED(DA/YR)=           |STRUCTURE-FIRES(#/YR)=         |CRB-SIZE-BK(100-CUYD)=          |-----------------------------------|
| COAL-REF-BURN(#/YR)=           |        COMMENTS=                                                                                  |
-----------------------------------------------------------------------------------------------------------------------------------
```

Figure 18. Area Source Emissions for St. Louis City

```
R                                                                                C
E                                                                      S         O
G               IPP INPUT DECK  (METRO. ST. LOUIS)                     T         U     T
I                                                                      A         N     Y
O          UTMX      AREA           SO2          NOX            CO     T         T     P
N      ID       UTMY        HGT            SP             HC           E         Y     E

070999917450790043100 250   33  0.0    0.0    0.0    0.0    0.0      14   520   A
070999917460790043150 250   33  0.0    0.0    0.0    0.0    0.0      14   520   A
0709999176207950429501000   33  0.148  0.084  0.168  0.409  1.628    14   520   A
0709999176307950430501000   33  0.078  0.046  0.143  0.304  1.285    14   520   A
0709999176407950431501000   33  0.149  0.082  0.159  0.390  1.553    14   520   A
070999917740800043250 250   33  0.023  0.015  0.123  0.222  1.013    14   520   A
0709999179408050429501000   33  0.052  0.033  0.169  0.323  1.433    14   520   A
0709999179508050430501000   33  0.541  0.297  0.448  1.212  4.644    14   520   A
0709999179608050431501000   33  0.058  0.036  0.158  0.310  1.355    14   520   A
070999917970805043250 250   33  0.060  0.076  1.387  2.332 11.001    14   520   A
0709999181508150429501000   33  0.063  0.038  0.160  0.316  1.377    14   520   A
0709999181608150430501000   33  0.177  0.096  0.174  0.435  1.711    14   520   A
0709999181708150431501000   33  0.069  0.040  0.155  0.313  1.356    14   520   A
070999916960765042600 250   33  0.001  0.000  0.001  0.000  0.001    14  1440   A
070999916970765042650  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999916980765042660  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999916990765042670  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917000765042680  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917010765042690  10   33  0.000  0.000  0.000  0.000  0.000    14  1440   A
070999917020765042700  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917030765042710  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917040765042720  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917050765042730  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917060765042740  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917070765042750 250   33  0.181  0.113  0.107  0.316  1.067    14  1440   A
070999917140786042650 160   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917150786042690  10   33  0.000  0.000  0.000  0.000  0.000    14  1440   A
070999917160786042700  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917170786042710 160   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917180787042690  10   33  0.081  0.050  0.040  0.130  0.424    14  1440   A
070999917190787042700  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917240788042690  10   33  0.000  0.000  0.000  0.000  0.000    14  1440   A
070999917250788042700  10   33  0.074  0.046  0.038  0.121  0.395    14  1440   A
070999917260789042690  10   33  0.000  0.000  0.000  0.000  0.000    14  1440   A
070999917270789042700  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917390790042600 250   33  0.001  0.000  0.001  0.000  0.001    14  1440   A
070999917400790042650 250   33  0.104  0.065  0.080  0.214  0.770    14  1440   A
070999917410790042700 250   33  0.001  0.000  0.001  0.000  0.001    14  1440   A
070999917420790042750 250   33  0.060  0.039  0.078  0.175  0.684    14  1440   A
070999917570795042650 250   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917580795042700 250   33  0.045  0.031  0.084  0.173  0.712    14  1440   A
07099991759079[illegible]   33  0.072  0.047  0.079  0.178  0.696    14  1440   A
07099991760079[illegible]   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
0709999176107950428501000   33  0.074  0.057  0.180  0.363  1.529    14  1440   A
070999917670800042650 250   33  0.049  0.033  0.064  0.178  0.731    14  1440   A
070999917680800042700  50   33  0.082  0.053  0.078  0.191  0.709    14  1440   A
070999917690800042750  40   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917700800042770  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917710800042780  10   33  0.000  0.000  0.000  0.000  0.000    14  1440   A
070999917720800042790  10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
070999917730800042800 250   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
07099991775080104277   10   33  0.0    0.0    0.0    0.0    0.0      14  1440   A
```

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Figure 19. Listing of IPP Input Cards Produced by CAASE

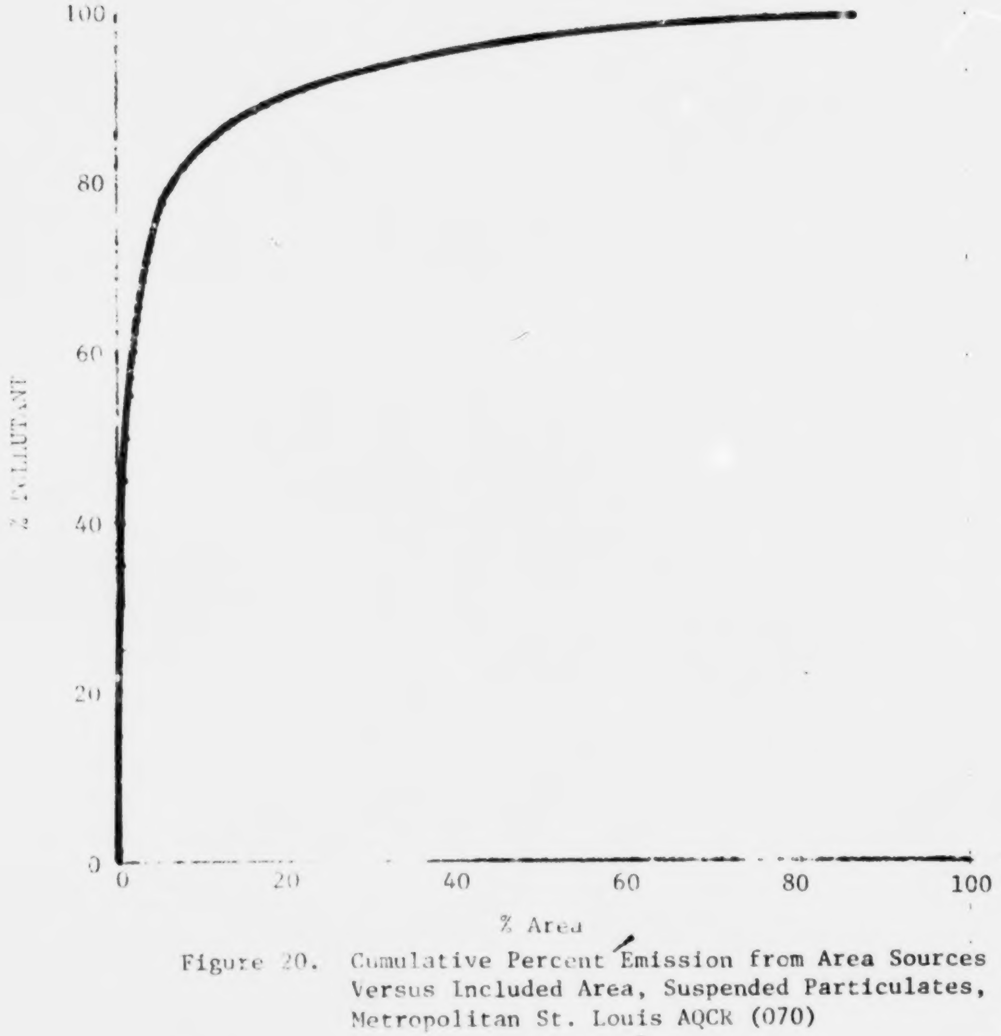

Figure 20. Cumulative Percent Emission from Area Sources Versus Included Area, Suspended Particulates, Metropolitan St. Louis AQCR (070)

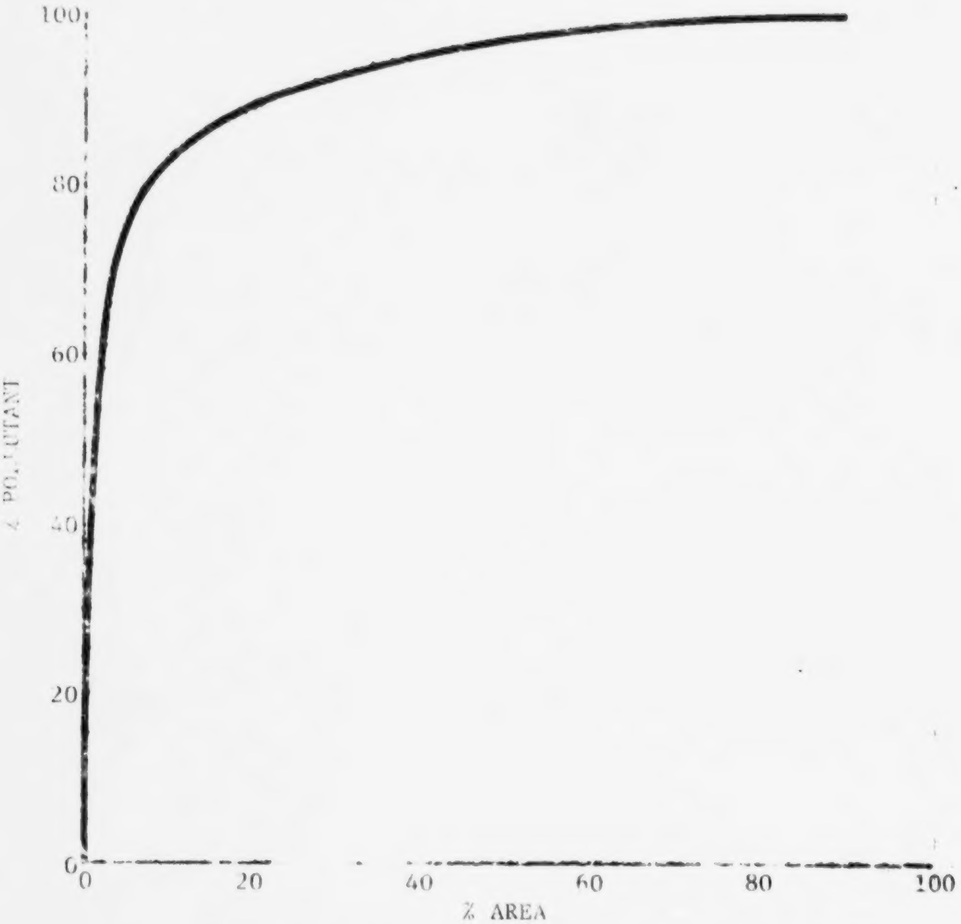

Figure 21. Cumulative Percent Emission from Area Sources Versus Included Area, Sulfur Dioxide, Metropolitan St. Louis AQCR (070)

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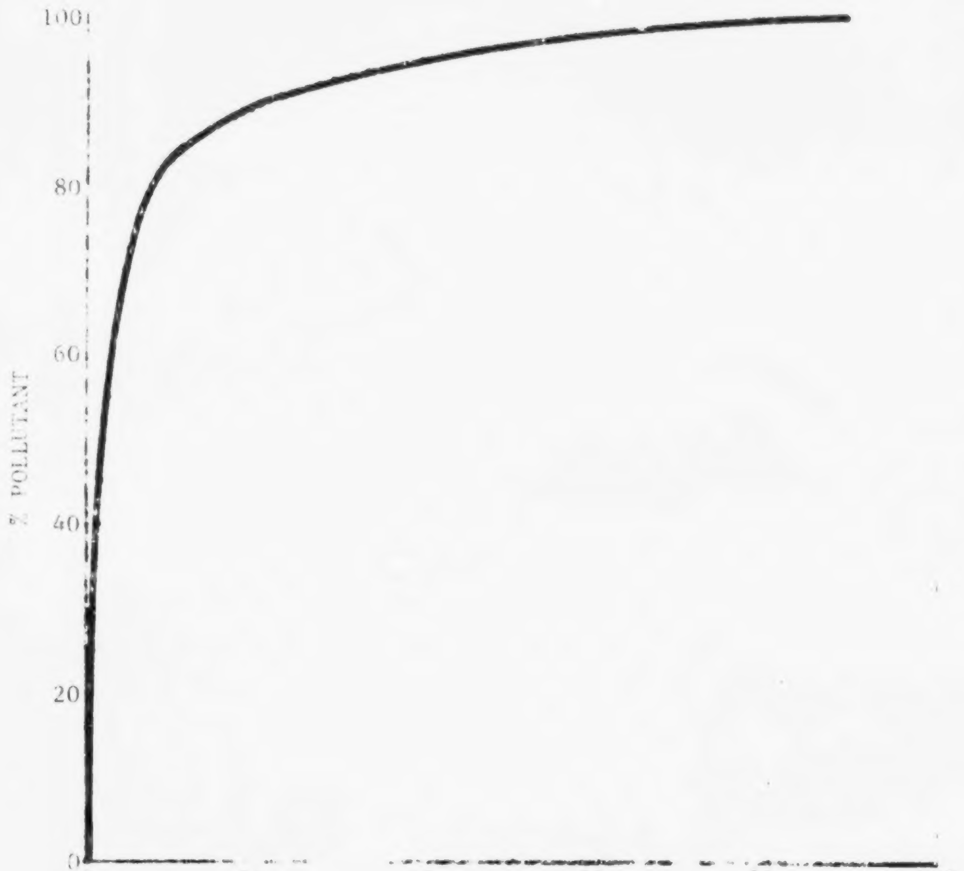

Figure 22. Cumulative Percent Emission from Area Sources Versus Included Area, Nitrogen Oxide, Metropolitan St. Louis AQCR (070)

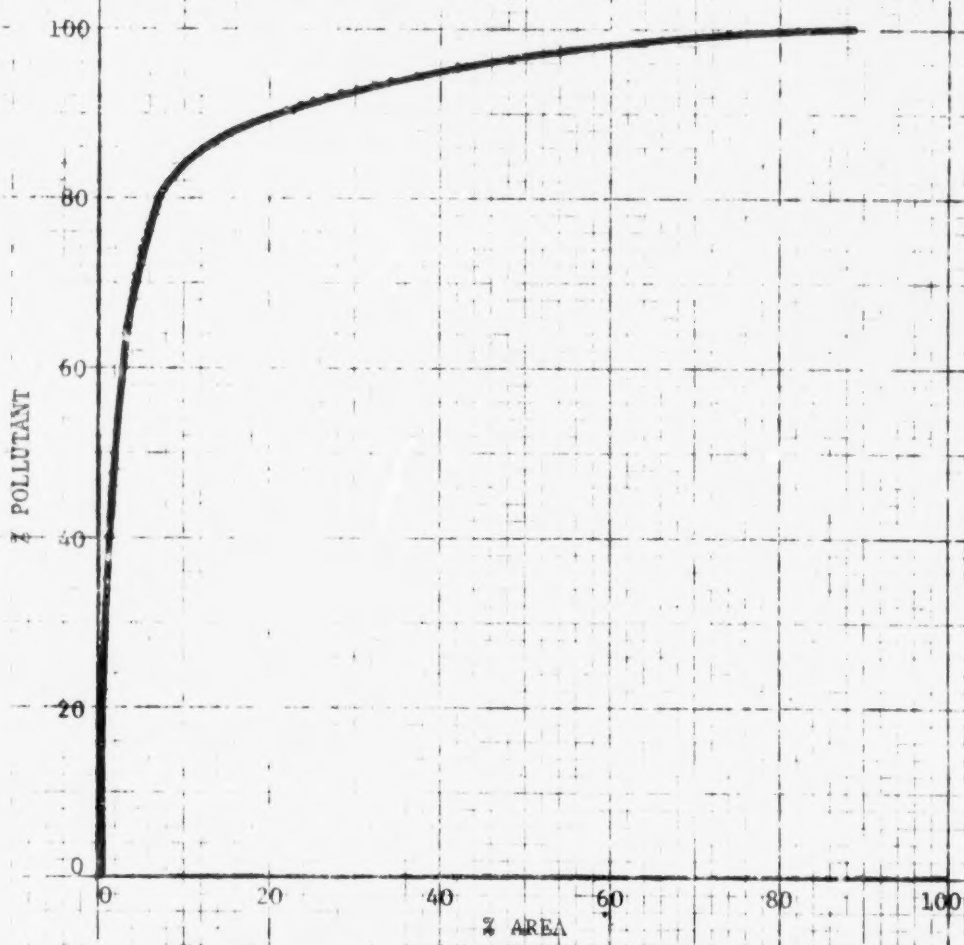

Figure 23. Cumulative Percent Emission from Area Sources Versus Included Area, Hydrocarbons, Metropolitan St. Louis AQCR (070)

Reproduced from best available copy.

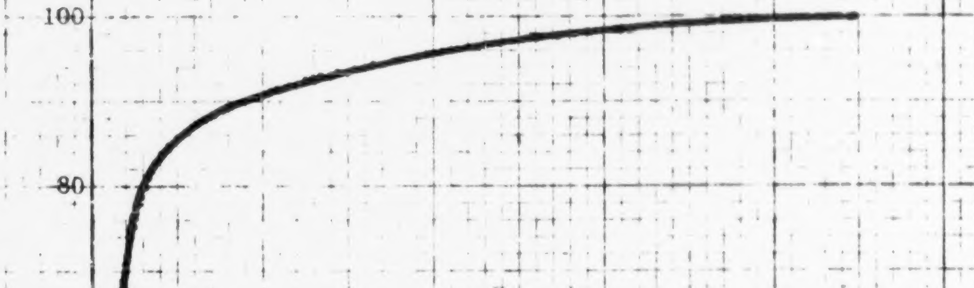

Figure 24. Cumulative Percent Emission from Area Sources Versus Included Area, Carbon Monoxide, Metropolitan St. Louis AQCR (070)

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OPTICALLY
REDUCED

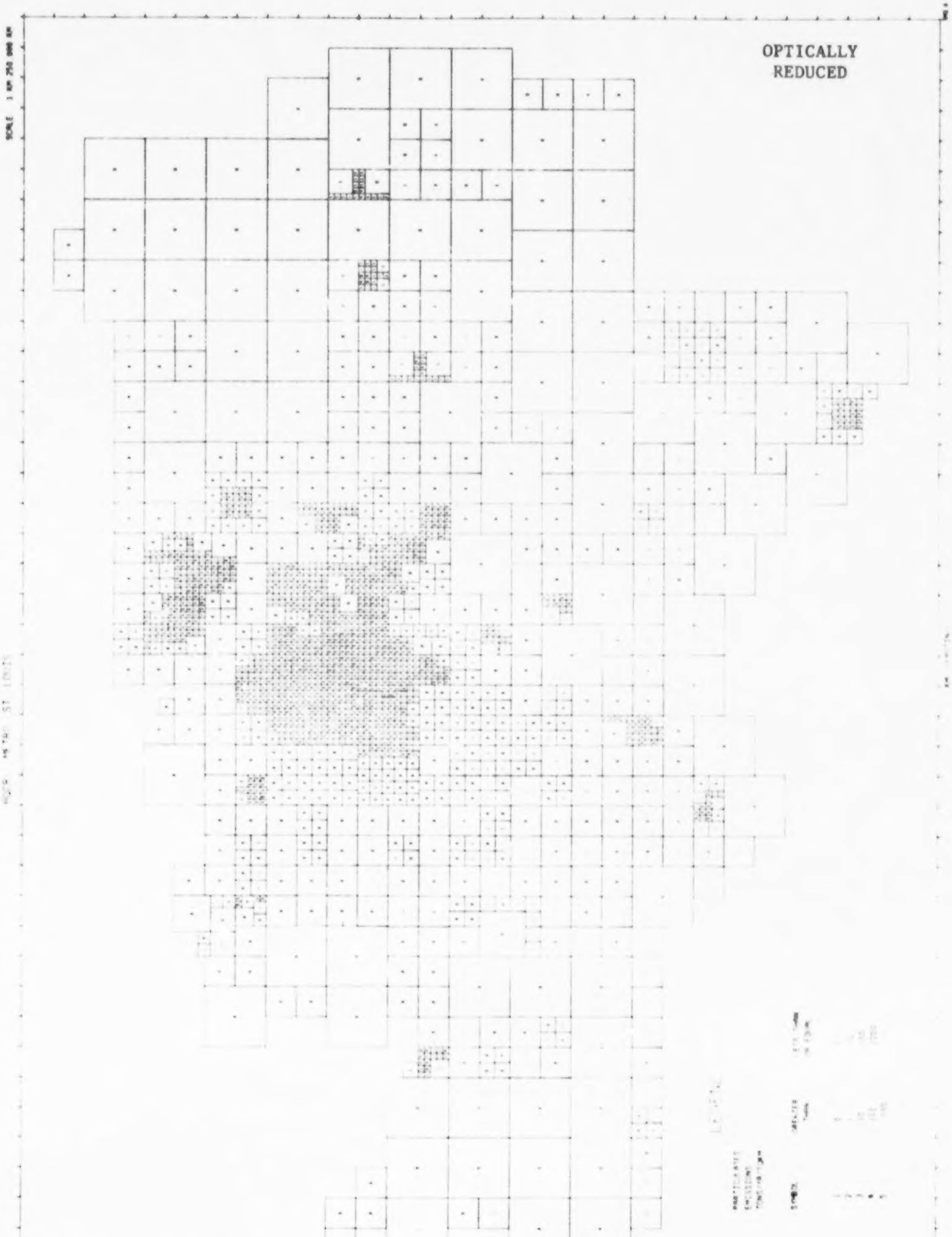


Figure 25. Example Emission Density Plot — Particulates

OPTICALLY
REDUCED

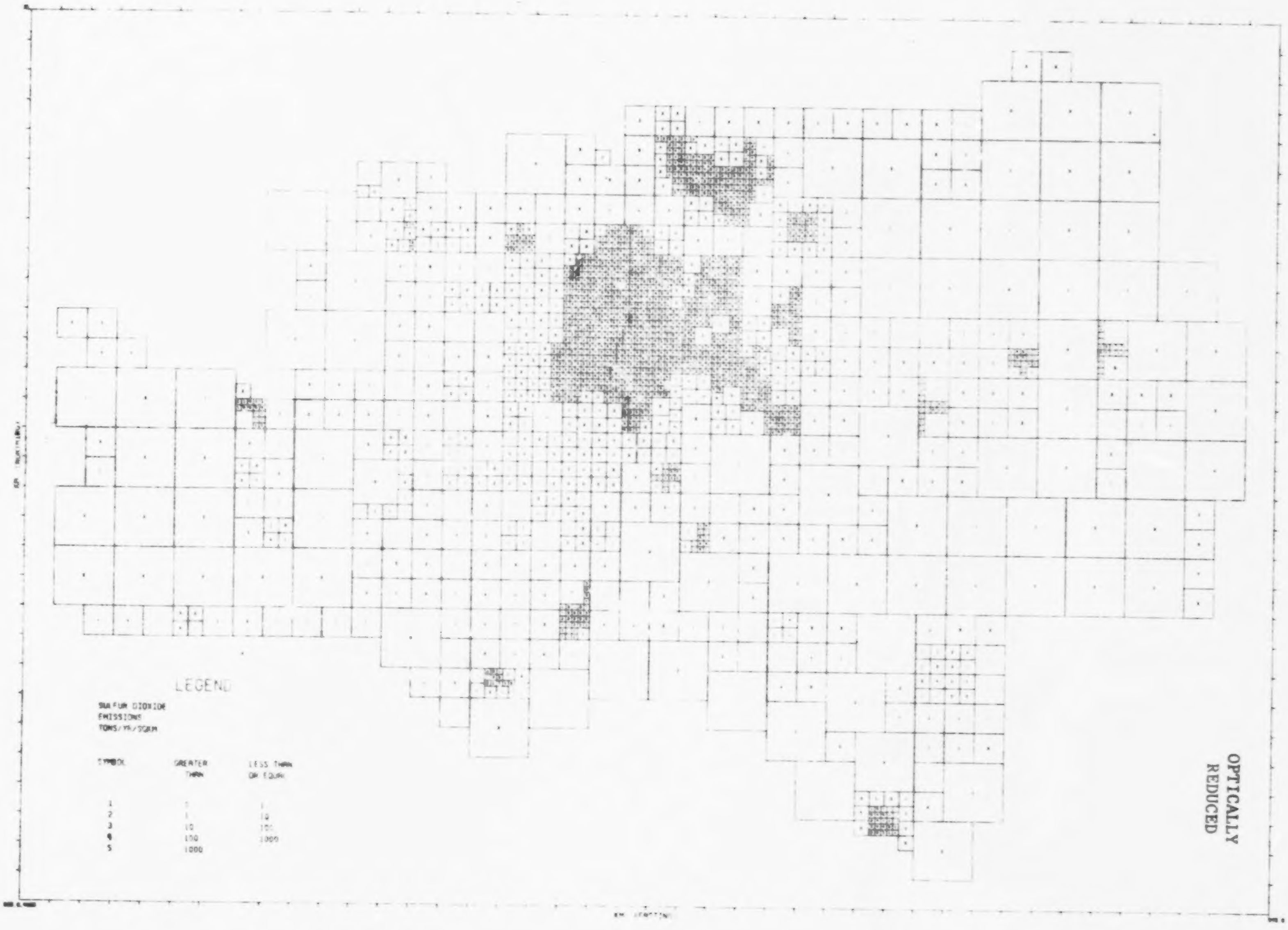
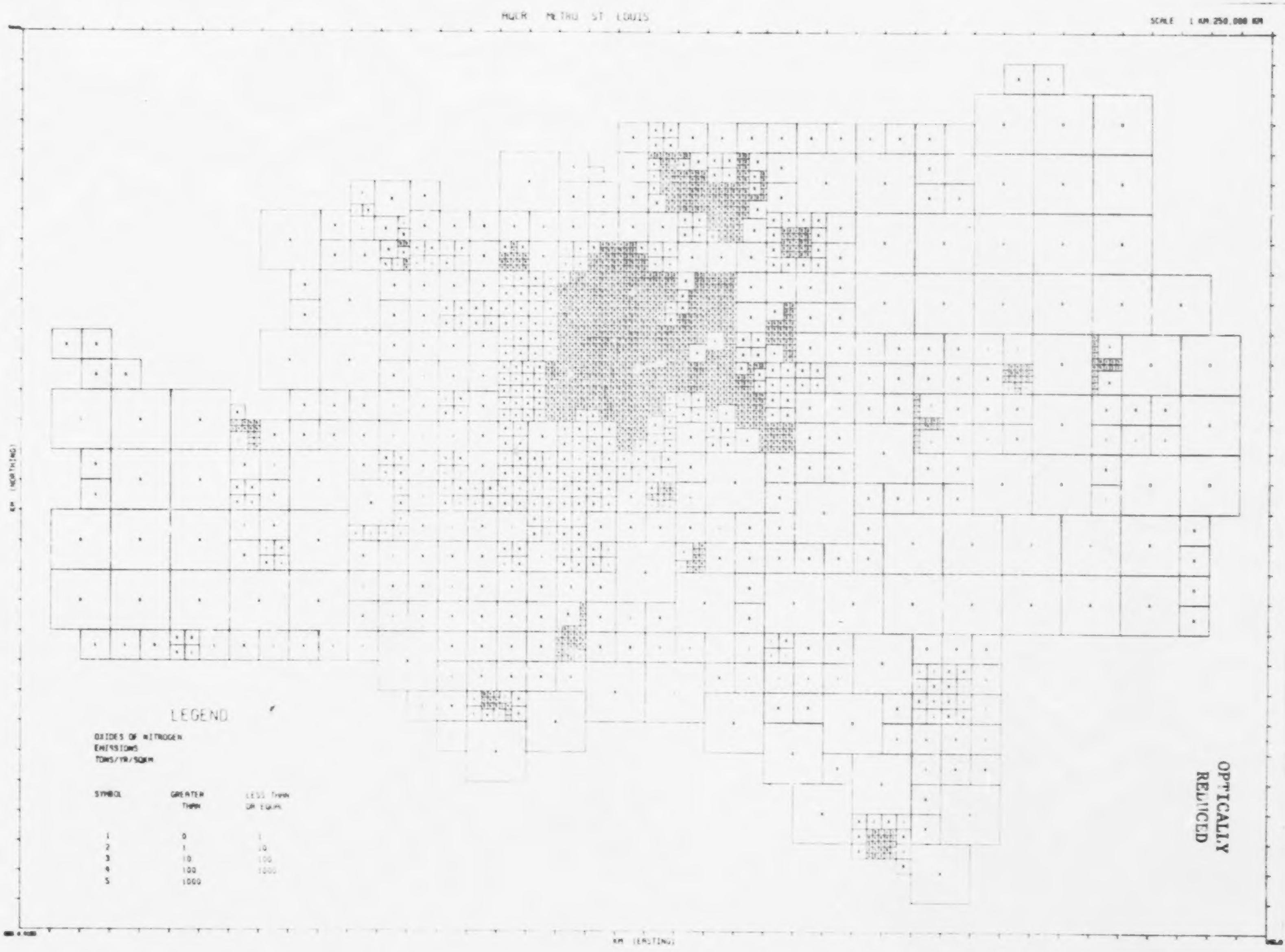

LEGEND
SULFUR DIOXIDE
EMISSIONS
TONS/YR/SQKM
SYMBOL
GREATER THAN
LESS THAN OR EQUAL
1
1
2
1
10
3
10
100
4
100
1000
5
1000

Figure 26. Example Emission Density Plot — Sulfur Dioxide


AQCR METRO ST LOUIS
SCALE 1 KM 250,000 KM
KM (NORTHING)
KM (EASTING)
LEGEND
OXIDES OF NITROGEN
EMISSIONS
TONS/YR/SQKM
SYMBOL
GREATER THAN
LESS THAN OR EQUAL
1 0 1
2 1 10
3 10 100
4 100 1000
5 1000

OPTICALLY REDUCED

Figure 27. Example Emission Density Plot — Oxides of Nitrogen

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OPTICALLY
REDUCED

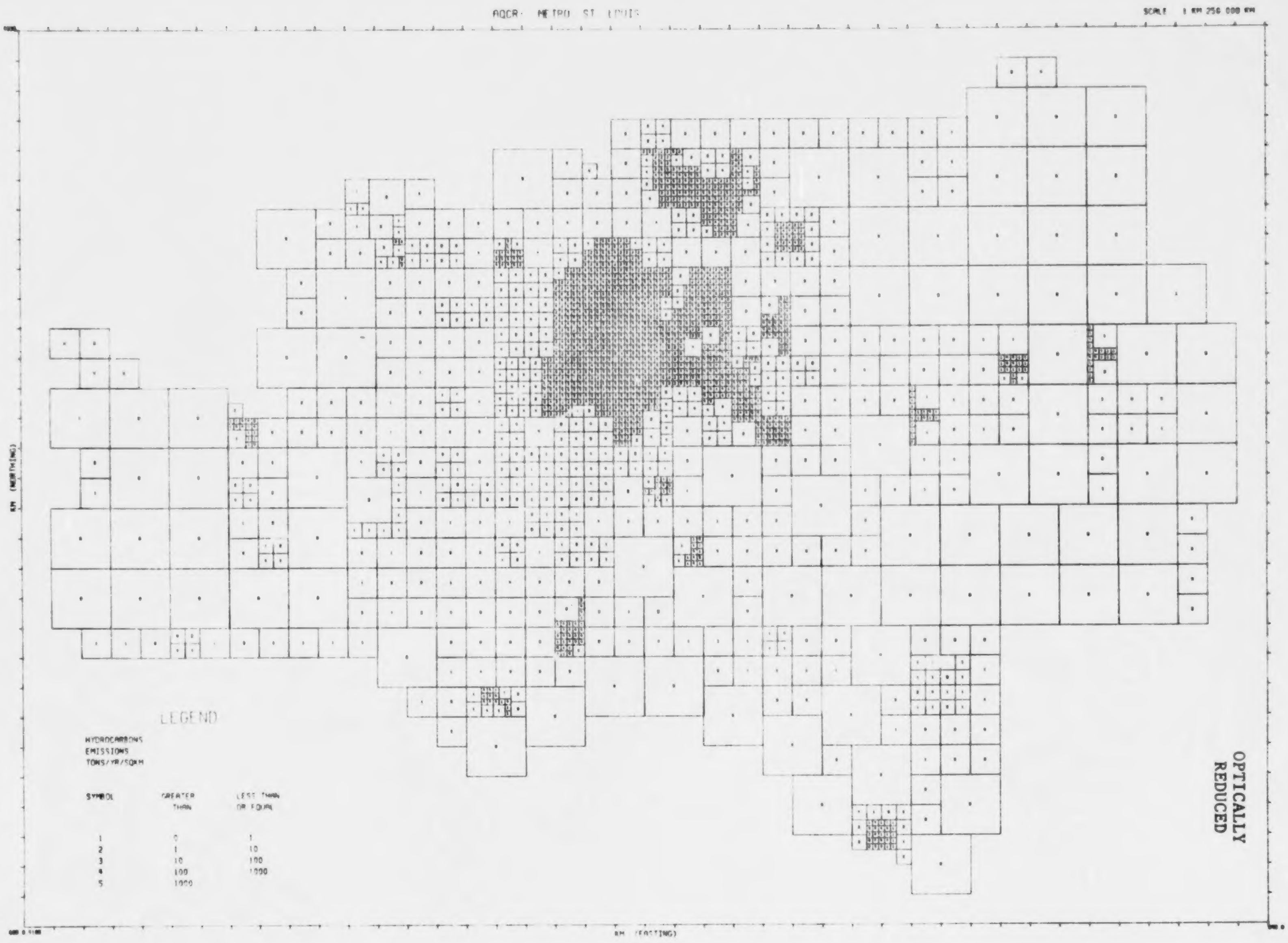
AQCR: METRO ST LOUIS
SCALE 1 KM
KM (NORTHING)
KM (EASTING)
LEGEND
HYDROCARBONS
EMISSIONS
TONS/YR/SQKM
SYMBOL
GREATER THAN
LESS THAN OR EQUAL
1 0 1
2 1 10
3 10 100
4 100 1000
5 1000

Figure 28. Example Emission Density Plot — Hydrocarbons

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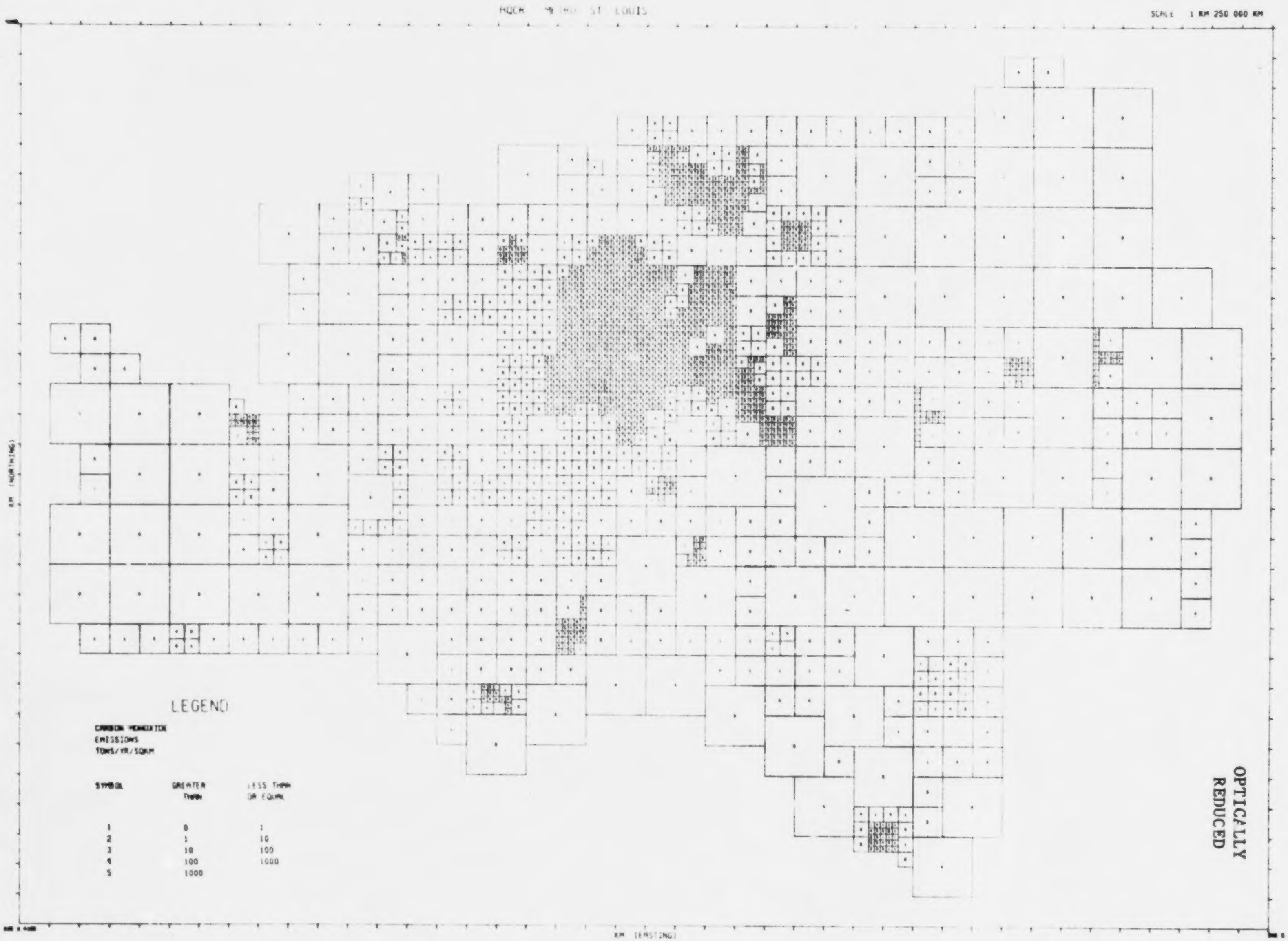
HQCR METRO ST LOUIS
SCALE 1 KM 250 000 KM
OPTICALLY REDUCED
LEGEND
CARBON MONOXIDE
EMISSIONS
TONS/YR/SQKM
SYMBOL
GREATER THAN
LESS THAN OR EQUAL
1
0
1
2
1
10
3
10
100
4
100
1000
5
1000
KM (EASTING)
KM (NORTHING)

Figure 29. Example Emission Density Plot — Carbon Monoxide

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GRID SQUARES RANK ORDERED ON EMISSION DENSITY FOR PARTICULATES

ID	COUNTY	STATE	UTM EASTING	UTM NORTHING	AREA SQ.KM.	EMISSIONS (TONS/YR) AREA	POINT	TOTAL EMISSIONS	TOTAL EMISSIONS/SQ.KM.
12[illegible]4	MADS	IL	750.0	4286.0	1.0	0.0	213075.000	213075.000	213075.000
1167	MADS	IL	748.0	4305.0	1.0	0.0	34650.500	34650.500	34650.500
1055	CLAR	IL	746.0	4275.0	1.0	4.742	8787.500	8792.242	8792.242
1074	MADS	IL	745.0	4263.0	1.0	0.727	5901.500	5902.227	5902.227
558	LOUI	MO	742.0	4276.0	1.0	119.352	4211.000	4330.352	4330.352
1332	MADS	IL	753.0	4302.0	1.0	0.0	3195.500	3195.500	3195.500
1303	MADS	IL	752.0	4306.0	1.0	64.605	1890.000	1954.605	1954.605
1648	RAND	IL	777.5	4200.5	1.0	0.0	1274.500	1274.500	1274.500
1200	MADS	IL	749.0	4309.0	1.0	3.285	1265.000	1268.285	1268.285
1364	MADS	IL	754.0	4302.0	1.0	0.0	1211.500	1211.500	1211.500
633	LOCY	MO	732.5	4265.0	6.3	45.625	7566.000	7611.625	1208.194
1007	LOUI	MO	743.0	4283.0	1.0	41.685	1014.500	1056.185	1056.185
1067	MADS	IL	745.0	4307.0	1.0	24.090	883.000	907.090	907.090
1513	CLAR	IL	761.0	4267.0	1.0	32.485	736.500	768.985	768.985
642	LOCY	MO	741.0	4250.0	1.0	10.220	683.500	693.720	693.720
615	LOUI	MO	738.0	4268.0	1.0	20.440	656.500	676.940	676.940
1122	CLAR	IL	747.0	4279.0	1.0	2.920	651.000	653.920	653.920
1050	MADS	IL	744.0	4309.0	1.0	13.505	547.000	560.505	560.505
524	LOCY	MO	729.0	4252.0	1.0	474.135	0.0	474.135	474.135
1133	MADS	IL	747.0	4307.0	1.0	5.840	452.500	458.340	458.340
557	LOUI	MO	742.0	4275.0	1.0	138.700	267.000	405.700	405.700
886	CLAR	IL	740.0	4265.0	9.0	11.315	3632.000	3643.315	404.813
675	LOCY	MO	734.0	4280.0	1.0	15.695	358.000	373.695	373.695
566	LOUI	MO	742.0	4264.0	1.0	93.605	256.000	349.605	349.605
757	LOUI	MO	736.0	4281.0	1.0	291.270	0.0	291.270	291.270
10[illegible]3	CLAR	IL	745.0	4265.0	25.0	14.965	6639.000	6653.965	266.158
712	LOUI	MO	735.0	4275.0	1.0	259.880	0.0	259.880	259.880
562	LOUI	MO	742.0	4260.0	1.0	258.420	0.0	258.420	258.420
759	LOUI	MO	736.0	4283.0	1.0	216.810	29.000	245.810	245.810
834	LOUI	MO	739.0	4275.0	1.0	243.455	0.0	243.455	243.455
751	LOUI	MO	736.0	4275.0	1.0	233.235	0.0	233.235	233.235
593	LOUI	MO	740.0	4261.0	1.0	231.410	0.0	231.410	231.410
750	LOUI	MO	736.0	4274.0	1.0	217.905	0.0	217.905	217.905
856	LOUI	MO	739.0	4277.0	1.0	217.905	0.0	217.905	217.905
670	LOUI	MO	734.0	4275.0	1.0	216.810	0.0	216.810	216.810
830	LOUI	MO	738.0	4283.0	1.0	210.970	0.0	210.970	210.970
534	LOUI	MO	741.0	4282.0	1.0	207.320	0.0	207.320	207.320
794	LOUI	MO	737.0	4283.0	1.0	199.290	0.0	199.290	199.290
893	LOUI	MO	740.0	4276.0	1.0	198.925	0.0	198.925	198.925
1127	MADS	IL	747.0	4286.0	1.0	36.865	162.000	198.865	198.865
928	LOUI	MO	741.0	4276.0	1.0	198.560	0.0	198.560	198.560
861	LOUI	MO	739.0	4262.0	1.0	198.195	0.0	198.195	198.195
793	LOUI	MO	737.0	4282.0	1.0	196.735	0.0	196.735	196.735
859	LOUI	MO	739.0	4280.0	1.0	196.735	0.0	196.735	196.735
497	JEFF	MO	729.0	4233.0	1.0	4.015	188.500	192.515	192.515

Figure 30. Listing of Grid Squares Rank Ordered on Density of Total Emissions for AQCR 070

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```
                LOCATION OF POINT SOURCES FOR METRO. ST. LOUIS

POINT SOURCE NUMBER    1 IS LOCATED IN GRID SQUARE NUMBER 1761
POINT SOURCE NUMBER    2 IS LOCATED IN GRID SQUARE NUMBER 1761
POINT SOURCE NUMBER    3 IS LOCATED IN GRID SQUARE NUMBER 1761
POINT SOURCE NUMBER    4 IS LOCATED IN GRID SQUARE NUMBER 1761
POINT SOURCE NUMBER    5 IS LOCATED IN GRID SQUARE NUMBER 1818
POINT SOURCE NUMBER    6 IS LOCATED IN GRID SQUARE NUMBER 1782
POINT SOURCE NUMBER    7 IS LOCATED IN GRID SQUARE NUMBER 1781
POINT SOURCE NUMBER    8 IS LOCATED IN GRID SQUARE NUMBER 1761
POINT SOURCE NUMBER    9 IS LOCATED IN GRID SQUARE NUMBER 1715
POINT SOURCE NUMBER   10 IS LOCATED IN GRID SQUARE NUMBER 1715
POINT SOURCE NUMBER   11 IS LOCATED IN GRID SQUARE NUMBER 1715
POINT SOURCE NUMBER   12 IS LOCATED IN GRID SQUARE NUMBER 1818
POINT SOURCE NUMBER   13 IS LOCATED IN GRID SQUARE NUMBER 1818
POINT SOURCE NUMBER   14 IS LOCATED IN GRID SQUARE NUMBER 1818
POINT SOURCE NUMBER   15 IS LOCATED IN GRID SQUARE NUMBER 1818
POINT SOURCE NUMBER   16 IS LOCATED IN GRID SQUARE NUMBER 1768
POINT SOURCE NUMBER   17 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   18 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   19 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   20 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   21 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   22 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   23 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   24 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   25 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   26 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   27 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   28 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   29 IS LOCATED IN GRID SQUARE NUMBER 1167
POINT SOURCE NUMBER   30 IS LOCATED IN GRID SQUARE NUMBER 1167
```

Figure 31. Listing of Grid Square Placement of Each Point Source in AQCR 070

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AQCR IS METRO. ST. LOUIS

OTHER ZONE	X-COORDINATE	Y-COORDINATE	COUNTY	PRIMARY ZONE	X-COORDINATE	Y-COORDINATE
16	280.9	4284.1	CLNT	15	802.9	4286.8
16	280.9	4284.1	CLNT	15	802.[illegible]	4286.8
16	280.9	4284.1	CLNT	15	802.9	4286.8
16	280.9	4284.1	CLNT	15	80 .9	4286.8
16	294.7	4275.1	CLNT	15	817.2	4278.8
16	280.5	4276.5	CLNT	15	802.9	4279.2
16	280.1	4276.0	CLNT	15	802.6	4278.7
16	280.1	4276.0	CLNT	15	802.6	4278.7
16	263.0	4266.0	CLNT	15	786.0	4265.6
16	263.0	4263.0	CLNT	15	786.0	4265.6
16	263.0	4258.0	CLNT	15	786.0	4269.6
16	294.7	4275.1	CLNT	15	817.2	4278.8
16	294.7	4275.1	CLNT	15	817.2	4278.8
16	294.7	4275.1	CLNT	15	817.2	4278.8
16	294.7	4275.1	CLNT	15	817.2	4278.8
16	276.2	4270.4	CLNT	15	801.1	4273.0
16	267.1	4292.2	MADS	15	788.5	4294.0
16	267.1	4292.2	MADS	15	788.5	4294.0
16	267.1	4292.2	MADS	15	788.5	4294.0
16	267.7	4292.5	MADS	15	789.1	4294.4
16	267.7	4292.5	MADS	15	789.1	4294.4
16	267.7	4292.5	MADS	15	789.1	4294.4
16	239.4	4266.6	MADS	15	762.6	4266.7
16	239.4	4266.6	MADS	15	762.6	4266.7
16	250.2	4231.7	RAND	15	775.6	4232.5
16	250.2	4231.7	RAND	15	775.6	4232.5
16	250.2	4231.7	RAND	15	775.6	4232.5
16	250.2	4231.7	RAND	15	775.6	4232.5
16	250.2	4231.7	RAND	15	775.6	4232.5
16	254.3	4197.6	RAND	15	781.9	4198.8
16	254.3	4197.6	RAND	15	781.9	4198.8
16	254.3	4197.6	RAND	15	781.9	4198.8
16	254.3	4197.6	RAND	15	781.9	4198.8
16	250.2	4199.7	RAND	15	777.7	4200.6
16	250.2	4199.7	RAND	15	777.7	4200.6
16	250.2	4199.7	RAND	15	777.7	4200.6
16	250.4	4199.6	RAND	15	777.9	4200.5
16	250.4	4199.6	RAND	15	777.9	4200.5
16	250.4	4199.6	RAND	15	777.9	4200.5
16	250.4	4199.6	RAND	15	777.9	4200.5
16	250.4	4199.6	RAND	15	777.9	4200.5
16	251.9	4199.8	RAND	15	779.4	4200.8
16	251.9	4199.8	RAND	15	779.4	4200.8
16	251.0	4269.5	CLAR	15	774.0	4270.3
16	251.0	4269.5	CLAR	15	774.0	4270.3
16	251.0	4269.5	CLAR	15	774.0	4270.3
16	251.0	4269.5	CLAR	15	774.0	4270.3
16	251.0	4269.5	CLAR	15	774.0	4270.3
16	251.0	4269.5	CLAR	15	774.0	4270.3
16	251.0	4269.5	CLAR	15	774.0	4270.3
16	251.0	4269.5	CLAR	15	774.0	4270.3
16	239.5	4266.0	CLAR	15	762.7	4266.1
16	239.9	4268.4	CLAR	15	763.0	4268.5
16	248.5	4246.0	CLAR	15	773.0	4246.7
16	255.2	4263.1	CLAR	15	778.6	4264.2
16	255.2	4263.1	CLAR	15	778.6	4264.2
16	255.2	4263.1	CLAR	15	778.6	4264.2
16	255.2	4263.1	CLAR	15	778.6	4264.2
16	255.2	4263.1	CLAR	15	778.6	4264.2
16	255.2	4263.1	CLAR	15	778.6	4264.2

Figure 32. List of Transferred Point Sources for AQCR 070

Scope of the Inventory

The primary requirements of RAPS in the emissions inventory field are for those pollutants which can be used as tracers in the modeling studies. Thus, initial emphasis was placed on sources of SO_2 emissions, since these are closely related to stationary sources of pollution. Based on the same reasoning, a carbon monoxide (CO) inventory should be assembled next, as this pollutant is virtually specific for mobile sources (automobiles). Similarly, a hydrocarbon and oxides of nitrogen inventory will be required for studies of reactions in the atmosphere, and a particulate inventory for research related to the role and dispersion of particulate matter.

In addition, several specialized inventories were also included:

- Non-criteria/Hazardous pollutants Inventory
- Heat Emissions Inventory

A more detailed discussion of pollutants of importance to RAPS is contained in the first portion of this section (1).

Two analytical techniques, which the National Air Data Branch has developed for use on NEDS emission data, will be used on the St. Louis data to obtain cost-benefit information. This information will provide guidance for maximum improvement of the emission inventory using available funds. The first is a sensitivity analysis (2), where an attempt is made to delineate the effect of source magnitude on the overall accuracy of the emissions inventory. The direct application of this type of analysis to the situation in St. Louis is discussed in Section F, under "Point Source Methodology".

The second is a statistical analysis of the precision of the emission inventory using a methodology developed by PEDCo (3). The last portion of this section deals with emission projections (4) and is presented to inform the reader of the different projection techniques that are available, the assumptions of each technique and the results of these techniques using the St. Louis AQCR as an example

1. RAPS Preliminary Emission Inventory, Stanford Research Institute, PB 232-223/AS, January 1974

2. Weighted Sensitivity Analysis Program, Federal Systems Division, IBM Contract No. 68-01-0398, Task I

3. Source Inventory and Emission Factor Analysis, PEDCo-Environmental Specialists, Contract No. 68-02-1350, September 1974

4. Emission Projections: Under development by the National Air Data Branch

POLLUTANTS OF IMPORTANCE TO RAPS

A. General Principles

1. Introduction

As is shown in Section C-3, there are numerous agencies and groups--both inside and outside the RAPS program--that have actual or potential needs for emission inventory data from the Saint Louis Air Quality Control Region (AQCR). Wide differences exist in the specific data requirements of these agencies, particularly with respect to the time resolution of the estimated emissions. However, the most demanding requirements are set by the need to verify experimentally various multi-source atmospheric dispersion (air quality) models. In particular, the emission inventories used for this purpose must provide a high degree of time resolution, giving emission estimates at one-hour intervals. A high degree of spatial resolution is also required.

Other possible users of emission inventories surveyed under Task A have generally far less demanding requirements. In particular, they do not commonly need the refinements of time resolution required for short-interval dispersion modeling. If they use the emission data for air quality modeling at all, it would probably be to estimate relatively long-term, average pollutant concentrations. Others may use inventory data only for surveillance and for determining the priorities for regulatory programs. In any case, the high-resolution emission inventory designed for use in dispersion model verification will be more than adequate for any of the other uses.

Attempts have been made previously to verify experimentally predictions of short-term air quality made from dispersion models. However, the source emission data fed into the dispersion models have been derived primarily from long-term average emissions (e.g., annual emissions), at least for stationary sources. Furthermore, most of the annual emission data have been derived by applying emission factors to survey information on fuel consumption and materials flow, rather than by making direct measurements. Estimates of hourly emmissions have been derived or extrapolated from the annual rates by more or less elaborate calculation procedures (see Section VII). The resulting compilation of extrapolation procedures, algorithms, and correlations for simulation of short-term emissions may be described, for lack of a better term, as an emission model. Unfortunately, the errors and uncertainties, both in the basic data and in the assumptions required for their extrapolation, are so great (or so indefinite) that estimates of hourly emissions derived from gross annual emissions cannot be relied upon for the critical tests of short-term air quality predictions to be carried out in RAPS.

At best, the predictions of pollutant concentrations from an air quality model can be no more precise than the source emission data used as input to the model. In addition to errors in emission data, other sources of error in the predictions, besides the inherent limitations of the dispersion model itself, include the description and measurement of the atmospheric structure, the measurement of the actual pollutant concentrations, and the representativeness of the pollutant concentrations actually measured. Assuming that sufficient care is exercised, we can estimate source emissions more accurately than any of the other input data to the air quality model. The level of effort needed to ensure the accuracy of the emission estimates rises rapidly as the required accuracy is increased, particularly as the time resolution is extended to shorter and shorter periods. Nevertheless, the emission estimates, being the least equivocal of the inputs to the air quality model, should be made accurately enough to ensure that they do not become the limiting factor in the testing of the model.

There is no practical way by which the emissions from all sources can actually be measured during the particular hours in which the test of an air quality model is carried out. Consequently, it is necessary to employ simulation techniques to estimate the hourly emissions from most sources, a process that also can be described as emission modeling. However, such emission modeling should involve as little extrapolation of data as possible. In particular, the emission model for a particular source should, where possible, contain an independent variable to be evaluated from data collected in real time at the source. Such data can, as in an extreme case, indicate whether the source was actually in operation during the period of time under consideration. In the general case, the data should indicate the value of some variable having a functional relationship to the emission. Most directly, in sources having continuous monitoring systems, the variable may be the concentration of the specified pollutant in the waste gas. In other cases, it may be a quantity such as the rate of firing of fuel. At all important sources, the relationship between the emission and the chosen independent variable should be established from actual measurements. Such measurements essentially constitute a calibration of the emission model. It will, of course, be necessary to redetermine the relationship between the independent variable and the emission (recalibrate the model) whenever there are significant changes in the mode of operation of the source.

It is feasible to carry out an emission inventory of the foregoing type for the Saint Louis AQCR and to store hourly values of the chosen independent variables and of the corresponding emission estimates for an appropriate period (for two or three years if desired). However, the process is necessarily difficult, time consuming, and expensive. It should therefore be carried out only for the minimum number of pollutants necessary for verification of atmospheric dispersion models; as discussed in Task A, these are considered to be SO_x, NO_x, HC, and CO. The inventory, which should be adequate for use in verification of mesoscale atmospheric dispersion models, may be designated as the RAPS Emission Inventory.

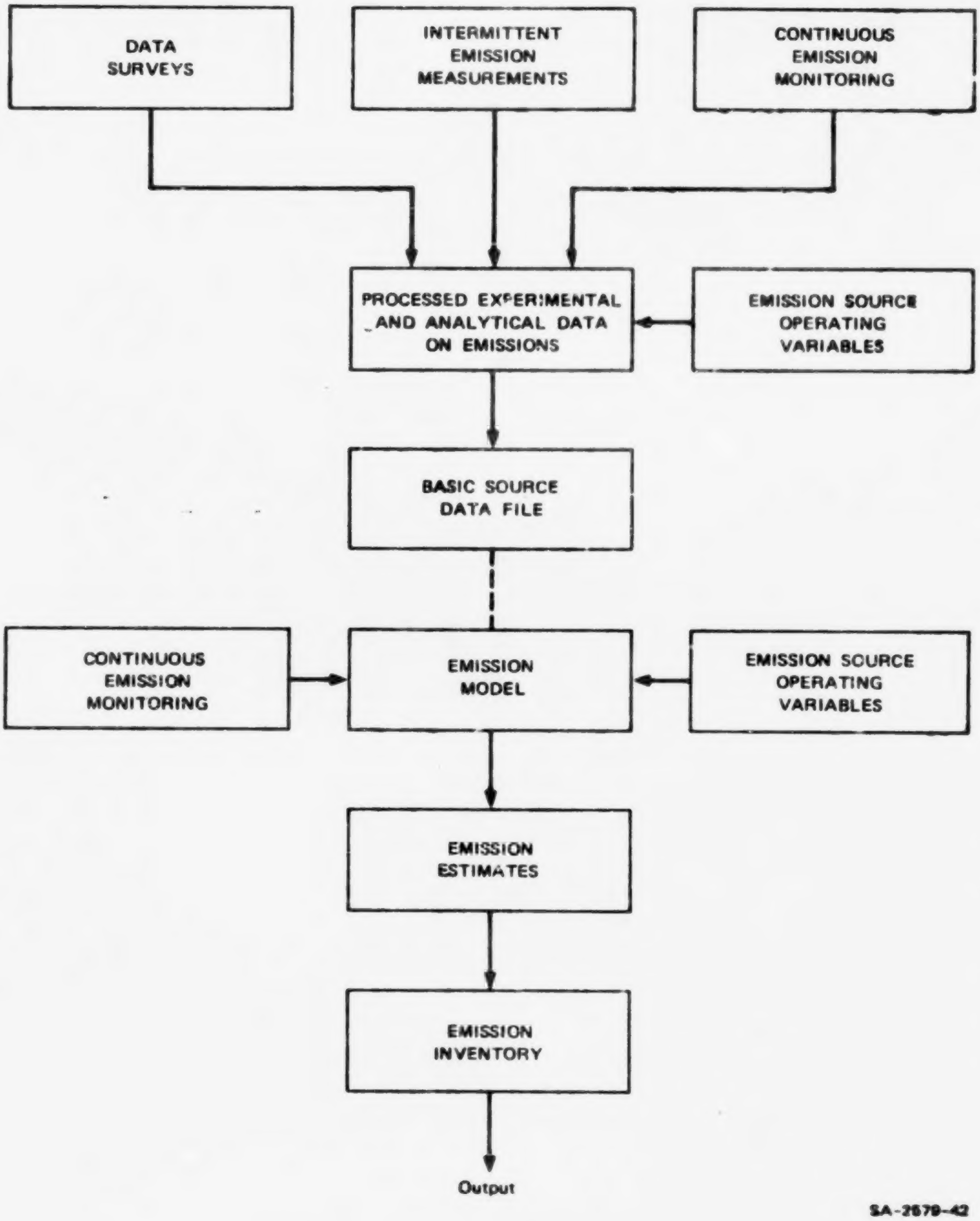
It should be appreciated that the RAPS Emission Inventory will be essentially separate and distinct from the existing National Emissions Data System (NEDS) Inventory, which was compiled under far less demanding criteria. Some information from the NEDS Inventory will be useful in the RAPS Inventory; for example, the NEDS Inventory locates and identifies stationary point emission sources and indicates their relative magnitudes. Some of the data in the NEDS Inventory relative to area sources and some small point sources may be, if carefully evaluated, adequate for inclusion in the RAPS Inventory. In addition, NEDS will provide the needed data on emissions for purposes that do not require high resolution data of the principle pollutants covered by the RAPS Emission Inventory.

For some anticipated microscale atmospheric dispersion studies, very high degrees of temporal and spatial resolution of emissions may be required for specific, small areas. Again, for particular studies, higher resolution data may be required for a pollutant and included in the RAPS Emission Inventory. The precise requirements for emissions data in such cases will vary considerably, and cannot be anticipated at this time. Specification and execution of these special emission data collections are basically research tasks that will be best handled by the research project staff carrying on the dispersion studies.

2. The Emission Inventory System

The following discussion is intended to provide an understanding of the general process by which information is generated and flows through the proposed RAPS Emission Inventory system and is intended to present definitions of terms (see Figure 2).

It should be appreciated that, whereas the eventual emission inventory is organized primarily according to pollutants, the execution of the inventory is necessarily organized primarily according to sources (the manner in which the original data must be obtained). The process


DATA SURVEYS
INTERMITTENT EMISSION MEASUREMENTS
CONTINUOUS EMISSION MONITORING
PROCESSED EXPERIMENTAL AND ANALYTICAL DATA ON EMISSIONS
EMISSION SOURCE OPERATING VARIABLES
BASIC SOURCE DATA FILE
CONTINUOUS EMISSION MONITORING
EMISSION MODEL
EMISSION SOURCE OPERATING VARIABLES
EMISSION ESTIMATES
EMISSION INVENTORY
Output

SA-2579-42

FIGURE 2 EMISSION INVENTORY SYSTEM

by which the RAPS inventory is to be carried out is essentially conventional; however, the special emphasis on and treatment of certain steps is determined by the high degree of temporal and spatial resolution required to meet the specific requirements of RAPS such as verification of atmospheric dispersion models.

Original information from emission sources is to be compiled from data surveys and, as far as possible, directly from intermittent measurements or continuous monitoring of the sources themselves. Subsidiary data on the operating variables and parameters of the sources must be collected so that correlations can be made between the variables and parameters and the actual measured emissions. The source variables are to be quantities that are--or can be--routinely measured as part of the source operation. Hence, once a correlation is established, the measurement of the variable can be substituted for the more difficult operation of measuring the actual pollutant emission.

For a relatively small number of the largest point sources, it is anticipated that continuous analyzers will be installed to monitor the concentration of key pollutants (SO_2 and NO_x). For the remaining point sources as far as practicable, reliance must be placed on intermittent manual measurements of emissions correlated with continuously measured process variables as described above, rather than upon the use of existing emission factors, although the latter can be used in certain cases.

For the smaller point sources, and for area and line sources (stationary and mobile), individual emission measurements will not be made, but more accurate emission factors than are currently available for typical sources must be derived from a sampling program.

Processing procedures for the raw data will depend on the nature of the information. At least initially, computation of the emissions from raw experimental data will probably be most conveniently carried out manually. Once the processed data is suitably organized, it is to be stored in the Basic Source Data File, which then is the source of information required for creation of the Emission Model for each source category of sources.

The emission model in this context is essentially a collection of correlations or algorithms that permit calculation of estimated emissions from readily or routinely measured operating variables and parameters of the various emission sources (as discussed above). The relationships must be worked out from the basic source data; they may range from simple to complex, depending on the nature of the emission sources.

To generate specific emission estimates, it will be necessary to supply to the emission model particular values of the independent emission source variables pertinent to the desired time interval. These input data must be collected from the sources on a continuing basis over whatever time period is required. The Emission Estimates thus generated provide the input to the Emission Inventory.

The Emission Inventory will consist of the compiled and stored estimates of the hourly emissions of the specified pollutants on an hourly basis for the time period (two or more years) of interest to the RAPS program. The emission estimates corresponding to any chosen sequence of one-hour intervals will then be withdrawn from the Emission Inventory to form input for the air quality models and other purposes.

B. Precision of Emission Estimates

Since the requirements for the emission inventory are to be set by the needs of dispersion modeling, it is necessary to specify, within some limits, what degree of agreement between predicted and measured pollutant concentrations will be considered to constitute a verification of a dispersion model. While the work of Hilst[9] discussed below approaches this issue, no such specification of model precision has been made. Modelers have thus far simply striven to obtain the best results that they could get. In tests of models made to date, it has been common to encounter deviations of ±50 to 100 percent or more between predicted short-term pollutant concentrations and the measured values. Better results are reported for prediction of long-term average concentrations.

An ideal multisource atmospheric dispersion model would permit accurate prediction of the concentration of a specified pollutant at any desired point in the geographical region of interest over as short a time interval as might be of practical interest. In practice, it is necessary to compromise the requirements for the model with respect to both temporal and spatial resolution. In addition to the inherent limitations of a model itself, the precision of measurement of emissions and meteorological variables and the practicability and precision of measuring atmospheric pollutants in the field set practical lower limits on the time intervals and the receptor areas that can be considered.

The predicted pollutant concentration is assumed to represent the average value within one square kilometer, which is the smallest element of the standard geographical coordinate grid. The pollutant concentration measured by a single monitor will bear a relation to the average concentration that will be determined by the distribution of the pollutant over the specified area. The distribution of the pollutant will depend on the geographical and topographical characteristics of the area. The distribution will therefore vary not only from one grid area to another, but also within any one grid area under different circumstances and at different times.

Other experimental studies in the RAPS program are expected to address the problem of the spatial variation of pollution concentrations within the receptor area. However, where it is necessary to employ a single monitor for one square kilometer area, the relationship of the measured concentration to the true average concentration for the area will necessarily be statistical and subject to a greater or lesser degree of uncertainty.

For such studies, or the development of microscale submodels designed to couple the regional scale models to specific localities or points where measurements are made or air pollution effects are significant, special efforts must be made to collect detailed emission data on an experimental basis. The routinely collected data of the RAPS Emission Inventory should be designed to serve the broader scale needs of the modelers on a continuing basis.

It will be important, however, to make a special check in the vicinity of each permanent monitoring station (say within a radius of one kilometer) to ensure that any point or other source that could significantly effect the representativeness of readings made at the monitoring station, are taken into account. For example, it may be found necessary to treat an office building heater system efflux as a specially considered point source, rather than as part of a nonspecified area source. Alternatively, if such consideration cannot be made in connection with the emission inventory system, steps should be taken by those responsible for air quality monitoring to develop weighting or calibration factors for the station in question, or even to set its readings aside for certain purposes under particular wind conditions

As stated above, it is essential that the precision of the pollutant emission data not limit the precision of the dispersion model. The difficulty of attaining highly precise measurements or estimations of pollutant emissions increases rapidly as time intervals are shortened. Hence, it is necessary to make compromises between precision and the cost and difficulty of measurement and estimation.

The question of the significance of errors in specifying the strength or location of sources has been addressed in Section VII, especially in terms of the precision needed in defining position. The sensitivity of air quality models to such errors is a complicated question and specific to each model and each area. The work of Hilst[9] in a case study of the TRC Model in Connecticut is indicative of what can and should be done for the major models to be tested in the RAPS program. Depending upon the resolution in space and time of the predictions made by an air quality model, Hilst's findings in New England are encouraging because the cancelling effect of random uncertainties minimizes the errors due to inaccurate point source data. Most serious errors can result from systematic inaccuracies, such as those introduced by incorrectly estimating area sources, and the smaller the proportion of the total inventory reported in this way the better. It is recommended that as early as possible, specific studies (based initially on NEDS data) of the type reported by Hilst be performed to provide information on the effects of varying the degree of precision of emissions data in Saint Louis, especially in terms of hourly resolution. In the meantime, it is highly desirable to develop the most detailed and accurate emissions database economically feasible in Saint Louis, both to ensure the best support of the air quality model studies and to provide the base data for research in emission modeling methodology.

C. Inventory Resolution

1. Temporal Resolution

As is indicated above, the difficulties both of formulating an adequate dispersion model and of testing it increase rapidly as the time interval is shortened. Ideally, a model should be capable of predicting the atmospheric concentration of a pollutant over the shortest interval for which an air quality standard is specified. In fact, it is probably impractical to specify an interval shorter than one hour. One limitation is that it is practically impossible to specify significant values for the pollutant emissions from most sources for periods of less than one hour. Indeed, it is difficult even to make precise estimates of emissions for periods as short as one hour, at least without making direct measurements in the particular time interval of concern. In view of these considerations, the minimum time interval to be considered may be set at one hour. This degree of time resolution has been accepted by most modelers.

2. Spatial Resolution

Stationary sources fall into two categories: point sources and area sources. The distinction between the two is generally arbitrary; point sources are those having emissions of a specified pollutant in excess of some selected minimum value, and they are treated individually. Smaller sources within a selected region are aggregated, and their total emission is assumed to arise uniformly from the area.

Choice of the minimum emission rate for specification of a point source obviously depends on the nature of the pollutant and the ratio of the emission from the particular source to the total emission from all sources.

Specification of the location of a source, whether a point or an area, is to be made by reference to UTM coordinates. The precision required in specifying the position of a source is also partly related to the position of the receptor. Some dispersion modelers have asked that the position of point sources be determined within ±10 meters. From the standpoint of a nearby receptor, the physical size of the stack or vent may be appreciable; large stacks may be 10 meters or more in diameter, and some building vents may be still larger in their principal dimension. An objective method for determining the spatial resolution required is presented in Section VII.

The method enables one to estimate the allowable error Δy, in the cross wind position of a source (for any specified stack height, source strength, wind velocity, and stability conditions), as it affects pollutant concentrations at given downwind distances. "Allowable error" is defined arbitrarily by comparison with a reference source strength--e.g., the 100 tons/year commonly used as the lowest value for point sources, and a reference positional error--e.g., 100 m, the resolution of most current inventories.

Although such a high degree of precision in specifying location may only be necessary in a limited number of applications, it is recommended that wherever possible the location of point sources be reported with a resolution of ±10 meters. Although existing data (in NEDS) is only specified to ±100 meters, additional surveys of significant sources will have to be made in any case, and it would therefore be readily possible to obtain the further locational data at that time.

As noted above, verification of microscale dispersion models will generally be special exercises. They will require finer spatial resolution and more detailed specification for local sources than will be required for tests or use of the mesoscale models. This finer degree of resolution can be incorporated into the general emission inventory for the entire area covered by the major dispersion models. However, the additional time and cost required may not be justified, since the increased resolution will probably never be required except in relatively few small areas being treated in the microscale dispersion studies. It is more practical to make special, fine-resolution inventories for the particular limited areas of the microscale studies.

D. Pollutants

1. General Discussion

Initially, inventories must be carried out for those pollutants that are to be used in model verification. In principle, it would be desirable to carry out the inventories simultaneously for as many of the pollutants as possible, particularly where surveys of the same sources are involved. But in practice, it may not be entirely feasible to do this, because the basic data may simply not be available for all of the pollutants at the same time. Acquisition of adequate data on emissions of nitrogen oxides and hydrocarbons will probably take much longer than will the gathering of equivalent information for sulfur oxides.

2. Nonreactive Gases

Although none of the major pollutant gases that may be used in tests of dispersion models are actually nonreactive, both sulfur dioxide and carbon monoxide are relatively unreactive in relation to the time of dispersion that is of primary interest to dispersion model verification. Carbon monoxide is the more inert of the two. However, sulfur dioxide has the advantage that its reaction products (sulfuric acid mist and sulfates) can be traced by chemical analysis, whereas the identity of carbon monoxide is lost after reaction.

Carbon monoxide is best suited to testing models of dispersion from automotive sources, since these are by far the major sources of this pollutant. It will be necessary, nevertheless, to inventory stationary sources, since their contribution to the ambient concentration of carbon monoxide may be appreciable in relation to the model testing.

It has been found that large quantities of carbon monoxide are produced in nature by the oxidation of methane in the atmosphere. Carbon monoxide is removed from the atmosphere by microorganisms in the soil. The background concentration of carbon monoxide in the atmosphere is determined by the balance of the natural removal processes and of the natural and anthropogenic formation of the compound. It is unlikely that either natural formation or natural removal is important on the time scale of concern to the dispersion studies and within urban areas, where high concentrations of carbon monoxide may be generated. Task E presents a more detailed discussion of natural emissions.

Sulfur dioxide is best suited to use in testing of dispersion models for pollutants from stationary sources, since relatively little is emitted from mobile sources. It is more reactive than carbon monoxide and more subject in the atmosphere to the action of various removal processes. The oxidation of the sulfur dioxide to sulfur trioxide results in conversion to an aerosol (sulfuric acid mist), and subsequent or coincident reaction of the sulfuric acid with ammonia or other basic materials in the atmosphere results in formation of solid aerosols. If the time interval of interest to the dispersion study is no more than a few hours, these reactions will probably not be of great consequence. Fortunately, it is possible to sample for both sulfur dioxide and the sulfate aerosols and, thus, to deduce the probable history and dispersion pattern of the total sulfur originally being discharged to the atmosphere as sulfur dioxide. (About two to three percent of the sulfur emitted from combustion processes is usually already in the form of sulfur trioxide.)

Sulfur dioxide and its reaction products may be removed, or scavenged, from the atmosphere by a variety of mechanisms. The sulfur dioxide may be absorbed by vegetation or reactive solid surfaces or be adsorbed by a variety of solid surfaces. It may also be absorbed by rain drops. The sulfuric acid or sulfate aerosols may be rained out or washed out or may be mechanically deposited by inertial, diffusional, or gravitational mechanisms. In time, the aerosols will also coagulate, increasing the particle size and accentuating particle deposition by the inertial and gravitational mechanisms. The coagulation mechanism will be strongly affected by the total concentration of particulate matter present in the atmosphere

In general, the influence of the various removal or scavenging processes on sulfur dioxide should be much greater than the corresponding influence on carbon monoxide. Allowances must nevertheless be made for the depletion of both pollutants by the various removal processes, but determining these adjustments is, of course, a task separate from the emission inventory. Estimating the depletion of the emitted pollutants is, in fact, an inherent part of the formulation and development of the dispersion models. It will call for an extensive supporting experimental program.

3. Reactive Gases

The most important transformation process involving major air pollutants is the photochemical reaction of the nitrogen oxides with hydrocarbons to form PAN and ozone. The nitrogen oxides are contributed in roughly comparable amounts by both stationary and mobile sources, which also contribute the hydrocarbons. Consequently, it is necessary to devote comparable attention to an inventory of emissions of both of these types of pollutants from both classes of sources.

As they are present in waste gases at elevated temperatures, the nitrogen oxides are primarily in the form of nitric oxide (NO). Partial conversion of the NO to nitrogen dioxide (NO_2) takes place primarily after the waste gases are cooled and mixed with ambient air. There appears to be no compelling reason why the distribution of NO and NO_2 in the hot waste gases need be determined or specified as part of the emission inventory. The subsequent distribution of the two species in the atmosphere is, of course, of critical concern in the transformation models, but it will have to be determined from separate experimental and analytical studies.

Developing an inventory for nitrogen oxides presents special problems. Most of the nitrogen oxides are formed by fixation of atmospheric nitrogen at elevated temperatures in the combustion processes, and the quantity formed is dependent on the temperature reached, the residence time at high temperature, the size and configuration of furnace or other combustion devices, the amount of excess air present, and any other factors that may influence the time and temperature history of the combustion gases. The nature of the fuel also influences the formation of nitrogen oxides, primarily through those fuel properties that affect the time and temperature relationships--flame temperature and flame emissivity. Any nitrogen compounds in the fuel may also be partly oxidized. Hence, the quantity of nitrogen oxides emitted from a given piece of combustion equipment cannot be estimated from first principles by any currently available methods. Strictly, it must be determined experimentally for each device and each operating condition.

Fortunately, the range of variation in nitrogen oxides formation is not so great that reasonably representative values cannot be obtained by testing specific types of devices over appropriate ranges of operating conditions. Nevertheless, extensive source sampling will be required to obtain adequate information for a precise emissions inventory.

Inventory of the hydrocarbon gases and vapors presents a potentially complicated case because of the very large number of different organic compounds that may be emitted and that may also vary widely in photochemical reactivity. It is completely impractical even to attempt to inventory emissions compound by compound, except in instances where, for example, a relatively pure, known compound is lost by vaporization. Probably the most that can be done in a practical way is to identify the organic compounds by major groups or classes (e.g., paraffins, olefins,

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diolefins, aromatics, alcohols, ketones, and so on). For the most part, even this will require a major source-sampling program. Identification and quantitative determination of the classes of compounds, alone, will call for a large analytical effort. Hence, it is essential to keep the scale of the sampling and analysis to a minimum consistent with attainment of the program objectives.

4. Particulate Matter

The development of dispersion models for particulate matter, as well as efforts at verification, are well behind comparable developments for dispersion models for gases. The dispersion of particulate matter is more complex than that of gases, since the dynamics of the particles are strongly affected by the particle size, as are the removal processes that result in a decay of the particulate cloud. In addition, the nonspecific nature of most particulate matter makes it difficult, if not impossible, to identify the source of the material, trace its path from source to receptor, and allow for losses resulting from removal processes.

In using simple dispersion models, it has been common for workers to assume that all dust emitted from emission sources remains airborne and contributes to the resulting atmospheric concentration of suspended particulate matter at the receptor. Such an assumption is highly unrealistic, since relatively coarse particles will, in fact, tend to settle out. Relatively fine particles (about 10 microns in diameter and smaller) are frequently assumed to behave more or less like a gas; this is a fairly safe assumption, but one still subject to somewhat indeterminate errors.

Making a realistic test of models concerned with particulate formation or dispersion would require the following information:

- The quantity of particulate material emitted from each source and the distribution of effective particle sizes of the particulates. It should be noted that the effective particle size distribution, which may reflect particle flocculation, is not necessarily the same as the distribution that may be indicated by the measuring techniques commonly employed.

  The particle size should, of course, be expressed in terms of the Stokes diameter (i.e., the diameter of the equivalent spherical particle of the same density that would have the same terminal settling velocity as the particle in question).

- The extent to which particles of each size are deposited by removal processes during passage over the terrain between the source and the receptor. No essential quantitative information is available on these phenomena. The technical problem is similar to that of determining the efficiency of dust collection equipment in the collection of particles of various sizes. However, the studies of particle deposition from the open atmosphere are necessarily less controllable than experiments with dust collectors, and work in even the latter field is not well advanced from the standpoint of basic science and technology.

Determination of the mass emissions and particle-size distributions of particulates emitted from even the major sources alone would require a major experimental program. The experimental methods and procedures for determination of the effective particle size of the materials as emitted are still poorly developed. In addition, the study of particle deposition from the atmosphere calls for a far greater experimental effort. If a comprehensive effort is to be made at confirmation of particulate dispersion models using particulates normally discharged from various sources, a lengthy and costly preliminary experimental and theoretical investigation will be required. Although information on particulates is noted as a requirement by a number of users identified in Task A, there is no evidence that the implications of including such data have been seriously considered.

It is therefore open to question whether an attempt to verify particulate dispersion models should be made using the actual particulates emitted from various sources. An alternative procedure using particulate tracers may be usable with less preliminary work and less expense and at an earlier date.

Use of particulate as well as gaseous tracers has already been proposed as a part of the RAPS program for tracing wind movements and plume dispersion. Conversely, it is possible to use synthetic particulates prepared from tracer materials (e.g., dyestuffs) to test predictions of particulate concentrations at various receptor areas, and also to get a relatively direct measurement of the depletion of the particulate cloud in its movement from source to receptor. The synthetic particulate matter can be produced within reasonable ranges of desired particle size, and it can be discriminated from other particulate matter in the atmosphere by its chemical or physical characteristics. The most convenient materials of this kind are those that can be measured by colorimetric or fluorometric techniques.

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If the synthetic particulates can be used for the testing of the dispersion models, there will probably be no need to develop a particulate emission inventory that has a high degree of resolution with respect to time intervals and particle-size distributions. This will result in major savings of both cost and time.

For the other purposes of RAPS, e.g., research on transformation processes, there may be a need for detailed information on particulate concentrations with high temporal and spatial resolution. Because of the difficulties noted above, however, it is suggested that research studies for these purposes be planned to avoid, as far as possible, dependence upon general source emissions data. Better results can be achieved by special monitoring of only the critical sources in a carefully selected area. The alternative is an extremely costly and difficult inventory development program.

In summary, it is proposed that data on particulates should not be included in the high-resolution RAPS inventory emission, since the means are not currently at hand either to acquire the full range of data that may in principle be required or to employ the information effectively if it were obtained.

5. Other Pollutants

In the RAPS area, only a few agencies have indicated an interest in obtaining inventories of pollutants other than the major ones discussed above, and none of the agencies that did were concerned with short-term dispersion modeling. Local and state regulatory agencies were interested in emission inventories for desigrated hazardous air pollutants, including mercury, beryllium, cadmium, lead, and asbestos. They called only for quarterly or yearly average emission rates or, at most, for daily average emissions during air pollution episodes.

The CHESS program includes consideration of a wider number of trace materials as pollutants including cadmium, zinc, lead, mercury, chromium, vanadium, nickel, copper, manganese, asbestos, benzo-a-pyrene, and polychlorinated biphenyls. Although CHESS relies mainly on air concentration measurements obtained from its monitoring network, it will probably require estimates of relatively long-term average concentrations in the years before the air monitoring network was established. Thus, it may be necessary to prepare estimates of emission rates for these earlier periods, so that the atmospheric concentrations at those times can be calculated from use of dispersion models.

In general, there is little point in attempting to carry out emission inventories for pollutants other than the major ones discussed above until such time as the precise requirements are specified by the potential users. Variations in the required precision and the time and space resolution can greatly change the costs and time required for the inventory.

6. Heat and Water Vapor Releases

Although not pollutants, sensible heat and water vapor releases are of interest to meteorology and dispersion modeling because of their effects on atmospheric stability. Studies are now being made of the effects of the urban "heat island."[10] The sensible heat and water vapor content in waste gases can generally be calculated readily from data that will be collected in the course of the emission inventories for sulfur oxides, nitrogen oxides, and particulate matter. The heat transferred to the atmosphere by convection and radiation from the surfaces of buildings, paved areas, and the earth must, of course, be estimated by separate procedures not related to the emissions inventory.

The temperatures and volumetric flow rates of the waste gases will be part of the information collected during the inventories. Hence, it will be possible to calculate the sensible heat content of the gases above the ambient temperature level. For combustion processes, it will generally be possible to calculate the water vapor emission from the quantity and the hydrogen content of the fuel burned. For some other fuel-burning operations, such as direct-fired drying, the water vapor present in the waste gas will greatly exceed that formed by burning of the hydrogen in the fuel. However, the water vapor content of the gas may be obtained during the sampling for various pollutants. Sometimes data on the process may permit calculation of the water content of the gas.

G. Physical Aspects of Emission Sources

For purposes of dispersion modeling, it is essential to know not only the quantity of a pollutant emitted to the atmosphere but also the manner in which it is emitted. It is necessary to know the effective height from which the emitted pollutant can be assumed to start dispersing. Therefore, there must be sufficient information from which it will be possible to estimate the effective height of the plume of gas. The effective height of the plume is the sum of the physical height of the stack and of the plume rise, which is the distance that the plume ascends under the influence of its initial momentum and its buoyancy.

For small source units, such as those that constitute area sources, the water gases are usually discharged effectively at ground level. Even where the gases are discharged a short distance above the roof of a building, they will generally be carried quickly down to ground level. Hence, it is commonly assumed in dispersion modeling that the waste gases are discharged at ground level and that neither their initial temperature nor velocity influences subsequent dispersion.

For point sources, and particularly for the larger ones, the emission inventory data must be supplemented by data on the gas flow rate, temperature, pressure, and specific gravity, and on the physical height and diameter of the stack. Calculations of the plume rise require knowledge of the gas exit velocity and the stack inside diameter at the plane of discharge, and of the temperature and specific gravity of the gas. Calculation of the specific gravity of the gas requires knowledge of the composition of the gas stream including the amount of water vapor.

In addition to the data noted above, the inventory should include information on the layout of the source stack with respect to other structures. As a rule of thumb, a stack should be at least 2.5 times the height of the nearest structure; otherwise, the proximity of the other structure may lead to "downwash" of the gas from the stack and a consequent rapid descent of the plume to the ground. Short stacks projecting from the roof of a building are particularly subject to this kind of problem, and the role of the stack in securing dilution and dispersion of the gas is largely lost.

H. Units of Measurement

Many agencies continue to use English engineering units, and it is virtually certain that many of the data coming into the inventory will continue to be expressed in engineering units despite a growing preference for the metric system. It is undesirable to convert such data into metric units manually before storage in the inventory because of the large amount of time it would take plus the time required for checking for conversion errors.

It is recommended that the data be entered into computer storage in the same units in which they are originally received. The computer should then be programmed to convert the data to metric units, when they are recalled and printed out. This procedure will diminish the amount of manual processing that the data must undergo and still retain flexibility.

I. Specification of the RAPS Emission Inventory

1. General

While NEDS as a source of information on annual or long-term emissions from a broad range of pollutants, it is recommended that a special high resolution RAPS Emission Inventory be developed to provide hourly data emissions of SO_2, CO, NO_x, and HC in the form of direct statements of weight of pollutant emitted in kilograms each hour from each point or line source or area element, for the Saint Louis (AQCR). Locational data will be provided in UTM coordinates with a resolution of at least 0.1 kilometers for point sources. Mobile sources will be specified in terms of traffic links (with a resolution of approximately 0.02 kilometers) for major routes and of areas for secondary routes. Both for stationary and mobile sources, the area elements will reflect either the spatial resolution of the basic data from which the emissions are estimated (e.g., housing developments) or one kilometer grid squares, whichever is the smaller.

Information on the physical characteristics of point sources and the prime data used in compiling the inventory would also be provided. Although it is not considered practicable to develop comparable data for particulates, it is recommended that additional data on particulate emissions be collected to supplement the NEDS inventory, specifically data to distinguish between coarse and fine particulate emissions from the major sources.

For initial planning purposes we propose that only point sources emitting over 100 tons per year of each pollutant be considered individually. The estimation of emissions from such sources will be accomplished in classes according to the magnitude of each source as specified in detail below. We recommend that emissions data be based upon direct monitoring of emissions for the largest sources. For other major sources, direct monitoring of hourly fuel consumption operating or process data should be used as the basis for estimating emissions. For smaller point sources, we propose that emissions be estimated on the basis of generalized patterns of temporal variation of emission as a function of source type and using the best available data on fuel consumption, operating or process data (i.e., per shift, daily, weekly). In the limit, this approach approximates current practice in which annual totals of such data are used as a basis for modeling. For area sources, we recommend the use of modifications and adaptions of already available emission models. Similarly, for a first approach to assessing mobile course emissions, we recommend the use of available models. Improved mobile source models should be employed as they become available to provide higher quality data. A simple new model should be developed to estimate natural emissions of nonmethane hydrocarbons on summer days. In all cases, we propose that special testing efforts be carried out to ensure that the emission and conversion factors used to derive the emission estimates are as reliable as possible and have regard for the high temporal resolution required. Standard emission factors should be employed only if a review of the source on a case-by-case basis indicates that such a factor may be used with confidence in the particular case.

2. Point Sources

a. Classification by Size

It is convenient to classify point sources by size according to the amount of pollutant emitted annually.

- Class I, over 100,000 tons per year.
- Class II, over 10,000 but less than 100,000 tons per year.
- Class III, over 5,000 but less than 10,000 tons per year.
- Class IV, over 1,000 but less than 5,000 tons per year.
- Class V, over 100 but less than 1,000 tons per year.
- Class VI, over 1 but less than 100 tons per year.

The numbers of sources comprising these classes for SO_2, CO, NO_x, and HC and their contribution to the total burden in each case is shown in

Table 12 based upon NEDS data that is discussed in greater detail in Section VI.

As indicated by these classifications, a relatively few sources account for the bulk of the emissions.

The annual emissions, obtained from the NEDS inventory, although adequate for initial source classification, are not entirely representative of the probable contribution of the various sources to air quality at specific time periods. For example, units supplying steam for space heating will be operated only in periods of cold weather, and the actual emissions at that time will be higher than indicated by the annual average. Furthermore, the emission rate will follow a diurnal cycle even within a single day.

The foregoing considerations are important because reports from atmospheric dispersion studies have indicated that ground-level pollutant concentrations are disproportionately affected by local low-level pollutant emissions, even though the latter are individually small and contribute--individually or even collectively--only a minor percentage of the total pollutant emission from all sources. Thus, the smaller emission sources cannot be ignored even as part of the general RAPS inventory that is intended to supply emission estimates for use in mesoscale atmospheric dispersion models. They must be appropriately evaluated even though the effort required is more than proportionate to their relative contribution to the total emission. Within these reservations, the statistics noted in Table 13 provide a useful basis for assessing the general magnitude of the problems involved in developing a program of point source emission estimates and describing the approach recommended.

b. Data Acquisition Groups

We propose that point source emission data be derived in four broad groups according to the basic records used to estimate emissions.

Group I. Continuous emissions monitoring records

Group II. Continuous records of fuel consumption, operating, or process data

Group III. Short term, periodic records of fuel consumption, operating, or process data (per shift, day, or week)

Table 12

POLLUTANT SOURCES BY CLASS

Source Strength (tons pe. year)	SO$_2$				NO$_x$					CO				HC			
	Number of Sources	Cumulative Number of Sources	Percent of Total Emission	Cumulative Percent of Total Emission	Number of Sources	Cumulative Number of Sources	Percent of Total Emission	Cumulative Percent of Total Emission	Number of Sources Not Emitting SO$_2$	Number of Sources	Cumulative Number of Sources	Percent of Total Emission	Cumulative Percent of Total Emission	Number of Sources	Cumulative Number of Sources	Percent of Total Emission	Cumulative Percent of Total Emission
Class I (>100,000)	4	4	49.8	49.8						1	1	79.5	79.5				
Class II (10,000-100,000)	9	13	31.3	81.1	7	7	52	52		5	6	19.1	98.6				
Class III (5,000-10,000)	13	26	5.7	86.8	3	10	6	58		5	11	0.8	99.4				
Class IV (1,000-5,000)	41	67	7.0	93.8	14	24	8	66	4					23	23	58.7	58.7
Class V (100-1,000)	117	184	3.1	96.9	87	111	8.3	74.3	20	20	31	0.4	99.8	76	99	32.0	90.7
Class VI (1-100)	174	358	3.1	100	369	480	25.7	100	195	185	216	0.2	100.0	371	470	9.3	100

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Table 13

TENTATIVE WORKLOAD* FOR THE MONITORING OF SO_2 AND NO_x SOURCES

Group	Origin of Data	Number of Sources	Test Program		Cumulative Percent of Total Emissions	
			Percent of Sources Tested	Number of Sources Tested	SO_2	NO_x
Group I						
Continuous emission monitoring	Class I and II sources	13	75%	10	81	52
Group II						
Continuous fuel consumption, operating or process data monitoring	Class III sources Individual tests (8) Sample tests (3)	13	80	11	37	58
Group III						
Short-term fuel consumption operating or process data monitoring	Class IV sources (45) Individual tests (24) Sample tests (5)				94	66
	Approximately 20% of Class V (30) Individual tests (10) Sample tests (5)	75	59	44	95	70
		—	—	—	—	—
Total		101	65	65	95	70

---

*Based on estimates of testing program from Table 12 data.

Group IV. Long-term (semiannual or annual) records
or estimates of fuel consumption, operating,
or process data.

Within Groups II and III, a further distinction should be made between sources for which separate conversion or emission factors are established and those for which representative factors will be established. Data from Groups I, II, and III will be collected on an ongoing basis.

In principle, it would be desirable to deal with all sources under Group I. In practice, sources should be treated in the highest ranking group possible while maintaining regard for the costs and difficulties of so doing. A tentative work load is indicated in Table 13 for SO_2 and NO_x sources to show how the scope of effort can be analyzed and assessed. This shows that, by collecting data routinely from some 101 sources (of which 65 have been individually tested), approximately 95 percent of the hourly SO_2 emissions and 70 percent of the hourly NO_x emissions can be estimated on a direct basis. Similarly, over 90 percent of the emissions of CO sources can be estimated on an hourly basis by the treatment of direct data from only six sources. Still, it would be necessary to obtain data from and test some 10 or more sources to achieve hourly estimates from direct data for only 50 percent of the HC emissions.

It is recommended that the method of grouping sources for this purpose be determined after a survey has been made of all the sources over 100 tons per year. This survey will produce a better understanding of the data available and the difficulty of collecting useful direct data on fuel consumption or operating or process data from which hourly emissions may be derived. Such a survey should preferably be made in site visits to obtain more details of the source and operations than are available from the NEDS review. It should ascertain the availability of direct monitoring data on emissions or fuel consumption and of operating or process data that can provide direct information on hourly emissions. Alternatively it should reveal the nature of short-term data from which hourly emission estimates can be derived. The survey should pay particular attention to the form of the available records, and the optimum frequency and method of collecting them.

The survey will provide a basis for determining how much special source testing is necessary to provide reliable conversion or emission factors for individual sources and possible categories of source. This survey would also reveal the needs and opportunities for installing appropriate monitoring devices at selected sources, an approach that could usefully upgrade the inputs from certain sources and reduce data collection effort.

It will be appreciated that the methodology proposed allows considerable flexibility in the manner in which sources are treated. In this way, optimum benefit may be derived from the available RAPS inventory budget on a case-by-case basis. In any limitation of effort for budgetary reasons, it would be preferable to reduce the numbers of sources treated individually, rather than to restrict the source testing program, since operating patterns may be more confidently determinable at the present time than emissions or conversion factors.

3. Point Combustion Sources

Combustion point sources burning oil and coal are responsible for most of the SO_2 emissions in the region, and are also major sources of NO_x. Those burning natural gas produce NO_x, but do not produce SO_2. Neither type of point source is a major source of CO or HC, particularly when compared with automotive sources, but their emissions of these pollutants are significant and must be considered in the context of RAPS.

The procedure for collecting emission data within the groups described in Table 13 is described here.

For each source, appropriate reference data, such as type of unit, nominal ratings, control equipment, and so forth, together with physical characteristics of the emissions point (i.e., stack height, diameter at the discharge, location of stack in UTM coordinates) must be compiled. In addition, critical fuel consumption, operating, or process data must be acquired in routine collections. These constitute data as a function of time, ascertained in the initial survey to be basic for the determination of emissions.

Typical of such data are

- Type of fuel (e.g., coal, oil, natural gas).
- Characteristics of fuel (e.g., sulfur and ash contents, higher heating value).
- Fuel-firing rate (e.g., weight or volume rate, thermal rate if available).
- For boiler furnaces, the steam generation rate at specified temperature and pressure.
- For power boiler furnaces, the steam generation rate and electric power output.

Then, the following procedures should be applied.

Group I: Directly Monitored Emission Sources--Most of the sources in Class I (over 10,000 tons per year of pollutants) are expected to be equipped with continuous monitoring devices for the measurement of SO_2 and NO_x and possibly with a Pitot element to measure flue gas flow continuously. Exit flue gas temperatures are likely to be recorded continuously at such large sources. The calibration of the permanently installed recorders will have to be verified experimentally unless data on such verification are available at the source. Similarly, flow measurements have to be obtained or verified. If no permanently installed Pitot element is on hand, such flow measurements will have to be correlated with a measured furnace operating parameter or variable. It may be advantageous to undertake the determination of other pollutants at the time of calibration. For example, from flue gas analysis, measurements of CO and hydrocarbons should be made, if the source is a significant (more than 100 tons per year) emitter of these pollutants.

Group II: Directly Monitored Fuel Consumption, Process, or Operating Data--Typically these are sources emitting less than 10,000 tons per year of SO_2 or NO_x but more than 5,000 tons per year and any larger sources not equipped with continuous monitoring devices. These units are not expected to have continuous monitoring systems for measurements of pollutant concentrations, but they should have good records of fuel consumption or other operating data with hourly resolution. In Group IIA, conversion factors are derived linking the continuously monitored parameter with the emission rates are derived from manual sampling at each source. This is carried out initially in the program and thereafter repeated intermittently to ensure the continuing validity of the results. In Group IIB, standard emission factors may be assigned to categories of similar sources after they are determined by testing representative stacks.

Group III: Short-Term, Measured Fuel Consumption, Processing, or Operating Data Available--In this group, in which both Class IV (1,000 to 5,000 tons per year) and Class V (100 to 1,000 tons per year) sources will be treated, records will be available on a shift, daily, or weekly basis for fuel consumption, process, or operating data. (Direct hourly data must be interpolated.) Again two possibilities are open. In Group IIIA, each plant is considered individually, and tests are made to establish both the time dependence and the amount of pollutant emissions that can be deduced from the recorded data. Appropriate conversion or emission factors are thus assigned to each source tested. In Group IIIB, factors are established for appropriate categories of similar sources on the basis of tests of representative samples.

Group IV: Long-Term Fuel Consumption, Processing, or Operating Data--For sources over 100 tons per year, for which suitable specific data are not available (or which must be treated in this fashion for budgetary reasons), we recommend the use of modeling procedures of the type described in Section VII. A suggested approach for SO_2 is to employ the Argonne[2] model, and for NO_x and HC the SAI model,[1,3] but with adaptation and modification to ensure that the best possible input data on fuel consumption are used and that conversion factors are verified by testing.

4. Point Noncombustion Sources

Because of the extreme diversity in point noncombustion sources, no general and detailed procedure for correlating emissions with source operating variables can be offered; appropriate procedures will have to be worked out, case by case, for each type of source, following the general principles outlined in Table 13 and in Section IV-E-2.

For the purpose of organizing the inventory, such sources should also be considered according to the most important pollutant that they emit. In this grouping, particulate emissions will not be used as a basis even though they may be the principal pollutant emitted by some sources.

J. Stationary Area Sources

1. General

Stationary area sources contribute minor proportions of the total burden of SO_2, NO_x, CO, or HC as described here. Their importance may be significant, however, in the context of RAPS, since they may contribute significantly to the concentrations of the key pollutants at the near-surface level on a local basis.

2. Area Combustion Sources

The NEDS inventory data indicate broadly that the emission sources in this category are primarily those using natural gas or distillate oils. Consequently, the estimated SO_2 emissions are minor (only about 1 percent of the estimated total). The relative contribution of NO_x from these sources is greater, but still a minor part of the total. The NEDS inventory indicates that 28 percent of the total NO_x emitted comes from area sources, but these include vehicles that are known to be, in the aggregate, a large contributor. The contributions of CO and hydrocarbons from the stationary area combustion sources are likely to be minimal.

As discussed, the only practical way to estimate short-term emission rates from the area sources is the use of simulation techniques such as are discussed in Section VII. The two most advanced models to date are the Argonne model[2] for SO_2 and the SAI model[1,3] for CO and NO_x. They are alone in their class in that they have received significant field verification. As discussed in Section VII, the models have limited precision for the estimation of area combustion source emissions for the RAPS inventory. Accordingly, it is suggested that to improve emissions estimates by such modeling techniques, more accurate and precise survey data on fuel consumptions as well as more accurate emission factors be obtained. Both will require that new experimental studies be made at typical sources.

Data on fuel consumptions in specific, small areas of cities are not readily available. Commonly, continuous metering of natural gas is carried on only at a few points on lines supplying major sections of the city. The flows metered at these points give no indication of the breakdown of usage by type of source, and the temporal variations in flow reflect only the summation of the demand patterns of different users. The consumption of gas by individual customers can, of course, be obtained from meter records. However, these will, at best, give only the monthly totals of gas consumed; they will not show the different uses by a given customer.

Data on fuel oil consumption by residential and commercial users are largely restricted to data on fuel oil sales. Even users will generally have no more than a qualitative idea of the actual rates of consumption over short periods.

To obtain a high degree of both temporal and spatial resolution in the estimates of emissions from area sources, it will be necessary to conduct extensive surveys of the patterns and amounts of fuel usage by representative sources. Sufficient sources must be surveyed to constitute statistically valid samples. It will probably be necessary to install meters at these sources that will record both the rates of fuel consumption at various times and the integrated total.

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Residential and commercial installations, in particular, will show marked diurnal variations in their fuel consumption patterns as well as variations in usage between week days and weekends or holidays. There will also be seasonal variations in the magnitude and distribution of fuel consumption. For example, the consumption of fuel for water heating may be relatively constant throughout the year, but the consumption for space heating will be highly seasonal. Because space heating will be the most highly variable as well as the largest consumer of fuel, the rate of fuel, consumption for this purpose should be correlated with ambient temperature.

Better emission factors must be obtained for the typical fuel-burning units used in residences and commercial establishments. Some required data may be derived from other studies currently in progress, but others will probably have to be made specifically to meet the needs of the RAPS inventory.

Once emissions are determined for the representative sources, the emissions from specific areas can be estimated from the number and sizes of residences and commercial establishments in the areas.

3. Area Noncombustion Sources

The only area noncombustion emission sources that appear to be significant are those emitting hydrocarbons and hydrocarbon derivatives (gasoline and solvents). The nature of the sources and their emissions was already discussed.

The release of solvent vapors from the painting of buildings probably cannot be incorporated in a practical way into models for prediction of hourly emission rates; the emissions are too irregular in quantity, time, and location. Probably also, the solvent emissions from this source are too small to be of concern in mesoscale dispersion studies. However, a painting operation might be of concern to a microscale dispersion study being conducted nearby. If so, making allowances for the emission is best handled as a project task of the dispersion study.

The area hydrocarbon sources of consistent importance will consist primarily of the smaller gasoline service stations and dry cleaning establishments. It will be necessary to survey the typical operating cycles of such establishments to establish the pattern of their emissions.

K. Mobile Source Procedures

For automotive mobile sources, we recommend that an average route speed model with a link or line source geometry supplemented with measured data of traffic flow (via fixed sensors on high volume freeways and selected arterials) be used.

The SAI (Systems Applications, Inc.) model[1,3] for hourly CO, NO_x, and HC emissions is recommended. It can have modified inputs derived from Stanford Research Institute's model[4] for spatial and temporal distribution of vehicle number and speed on a link basis for primary traffic and area basis for secondary traffic. As a basis for this approach, data should be assembled on traffic volumn and the location of the primary traffic links and of the areas of secondary traffic. Additionally, arrangements should be made to install and collect data from fixed sensors on selected routes, as noted above.

As soon as improved methodology is developed for refining the inputs to such models, it should be used to update the inventory, and, in due course, the simple average speed approach could be replaced by more comprehensive modeling techniques as they become available.

In any case, prime data relating to route links and such would be available from the RAPS Emission Inventory records for use in such model development or other purposes.

For other mobile sources the following models should be used to the extent possible:

- Geomet model[5] for diurnal emissions from river vessels and railroads.
- Northern Research and Engineering Model,[6] as revised by Geomet (in preparation), for aircraft emissions.

L. Natural Background Emissions

Techniques of estimating the natural emissions of nonmethane hydrocarbons in summer daytime should be developed so that such emissions may be added to the inventory in time for studies in which hydrocarbon emissions are considered.

M. Particulates

As noted, it is impracticable to develop a high resolution inventory of particulate emissions on a routine basis. For modeling studies it would appear that such emissions must be treated on a project basis with special collections of data (possibly limited in space and time) as required. In addition, it is suggested that the tracer technique be employed to investigate the dispersion of particulates under various conditions.

N. Scheduling and Scale of Effort

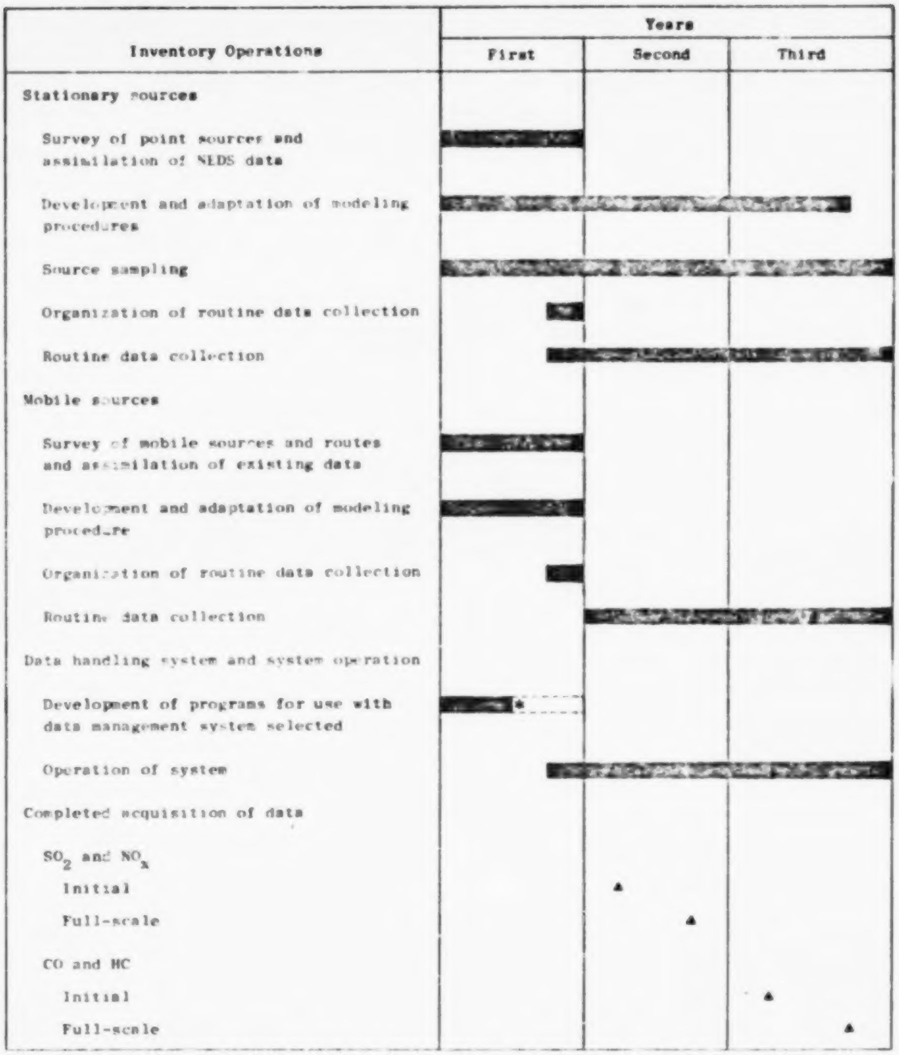
The development of a complete RAPS Emission Inventory is scheduled to take up to three years.

It would be desirable, however, to aim for an earlier provision of emissions data, especially for the first critical tests of air quality and dispersion models. These will use SO_2 (emphasizing stationary sources). Accordingly, the development of the inventory of these pollutants should be given priority, particularly in the source testing and modeling phases. (Since the majority of point sources of SO_2 also emit NO_x, the collection of data on this pollutant can conveniently be carried on in parallel.)

A possible schedule is shown in Table 14. The aim is to provide initial data on SO_2 and NO_x by the first quarter of the second year of full activities and complete data by the end of the third quarter of the second year. For CO and HC, effective initial data should become available by the end of the second year and complete data by the third quarter of that year.

Table 14

DEVELOPMENT SCHEDULE



Inventory Operations	Years		
	First	Second	Third
Stationary sources			
Survey of point sources and assimilation of NEDS data	▬		
Development and adaptation of modeling procedures	▬	▬	▬
Source sampling	▬	▬	▬
Organization of routine data collection	▬		
Routine data collection	▬	▬	▬
Mobile sources			
Survey of mobile sources and routes and assimilation of existing data	▬		
Development and adaptation of modeling procedure	▬		
Organization of routine data collection	▬		
Routine data collection		▬	▬
Data handling system and system operation			
Development of programs for use with data management system selected	▬ *		
Operation of system	▬	▬	▬
Completed acquisition of data			
SO_2 and NO_x			
Initial		▲	
Full-scale		▲	
CO and HC			
Initial			▲
Full-scale			▲

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*Additional effort if interface facilities of basic system need major extension.

EPA-450/3-74-022-a

WEIGHTED SENSITIVITY ANALYSIS OF EMISSIONS DATA:
VOLUME I -
BACKGROUND AND THEORY

by

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PREFACE

The project described in this report was performed under the auspices of the Environmental Protection Agency in conformance with Task Order No. 1, BOA68-01-0398.

The work performed as the Weighted Sensitivity Analysis of Emissions Data project proceeded with unusual effectiveness because of the excellent support provided by the Technical Project Monitor, Mr. John Bosch, and his associates. During the course of the project, Mr. Bosch gave much valuable assistance and guidance which led to the timely and successful completion of the project. Because of these efforts, it was possible to develop additional programs beyond those originally contemplated. The support of Mr. Gerald Nehls to provide basic and test data from the NEDS data was greatly appreciated and directly contributed to the capability to extend the study to include the SCC summarization program.

WEIGHTED SENSITIVITY ANALYSIS (WSA) OF EMISSION INVENTORIES

The IBM contractual report on weighted sensitivity analysis (WSA) allows users to quantitatively analyze the effects of potential inaccuracies in their air pollution source/emissions inventories. This enables the user to quantify the amount and direction of future resources he must allocate to maintain a given accuracy for his entire emissions inventory. The WSA is one of a series of management tools provided by EPA to effectively interpret emission and source inventories of air pollutant emitters.

WSA is based on the format used and data contained in the National Emissions Data System (NEDS), the official air pollution data base used by EPA. Because a number of States are patterning their emission inventories according to NEDS, the WSA with subsequent modifications is also expected to be useful to non-EPA users, especially to the pollution control agencies using the Comprehensive Data Handling System (CHDS).

The primary objective of WSA is to calculate the maximum allowable variation in emissions for each of the component sub-categories of the emission inventory. This is accomplished by the user first specifying an acceptable error in the total emissions of any criteria pollutant for the geographical area of interest (County, AQCR, State, U. S.). (This is referred to as θ in the WSA report.)

WSA then applies standard statistical techniques to the NEDS inventory for that geographical area and delivers an "allowable" error for over 100 sub-categories comprising all components of the emission inventory.

WSA calculates the maximum variance in emissions for each sub-category in order to maintain the previously=-specified error for the total inventory. It must be emphasized that WSA does not estimate the actual or existing emission errors for each sub-category: this can only be accomplished by accessing the rew data files of NEDS and estimating the errors due to emission calculations on an individual point and area source basis. An EPA contract is currently underway to perform this function (Source Inventory and Emission Factor Analysis; SIEFA) which will be complementary with WSA and will provide users with an integrated system for error analysis.

Four major assumptions were required for the successful development of WSA:

1. The "on-paper" inventory represents the "real-world" emissions. The necessity of this assumption is apparent: analysis of any data base presupposes that that data base is correct. Any analytical tool becomes more useful to users as the data which it utilizes become more complete.

2. The allowable errors calculated for each sub-category are assumed to be independent of each other. This assumption was necessary to develop the WSA analysis and is justified because any error interdependencies between sub-categories (e.g. population biases) are

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considered to be minor compared to the numerous other causes of emission errors for a given sub-category. It should be noted that the sub-category errors are considered to be independent and not the sub-category emissions.

3. Sub-category errors are considered to be random in nature. It is felt that this assumption is, in general, a valid one and WSA was designed with this definition. As described in the WSA report, however, there is a capability to "fix" sub-category errors when known by the user. In this manner, biased or random errors for an individual sub-category can be inserted into WSA whenever they are available. (In such cases, WSA recalculates allowable errors for the remaining sub-categories.)

4. WSA assumes that the distribution of component errors is unknown. This provides for a conservative estimate of the confidence limits to be attached to the θ's (defined in the WSA report as overall errors). There are no known means of estimating the distribution of emission inventory errors although SIEFA will eventually provide such a mechanism; thus the assumption of a normal error distribution seems inappropriate at this time.

It must be emphasized that in analyzing a small subset of inventory data the user should reevaluate the validity of the above WSA assumptions for his project before relying on the technique.

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Section I

INTRODUCTION

This final report documents the work performed under contract BOA 68-01-0398, "Weighted Sensitivity Analysis of Emissions Data". It presents a body of analytical techniques appropriate for determining accuracy requirements of component parts of an emissions inventory so as to insure (at a given confidence level) an overall acceptable accuracy in the total inventory. Selected numerical analyses are presented to illustrate application of the techniques to Nationwide Emissions Report (NER) data at different levels of aggregation. Contract work included development of the necessary software to implement the results of the analysis. The results are believed to constitute a significant step in the development of techniques for making reliable forecasts of air pollutant emissions, and have already been applied for such purposes to emissions in region 5 of the State of Virginia. A report on that application is also included in the present document.

PROJECT BACKGROUND

In 1969, NAPCA established a project called "Projected Growth Data for the Air Quality Control Regions"; in support of this project the U. S. Department of Commerce, Office of Business Economics (OBE), prepared the document, "Economic Projections for Air Quality Control Regions," (PB195805) in June 1970, in ample time to support the nationwide preparation of state air quality control implementation plans.

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The preparation of these projections entailed the application of sophisticated techniques by expert econometricians and the utilization of esoteric methodologies by specialists in the Regional Economics Division of OBE.

Although these projections were the best possible, there was no way of predetermining their accuracy or relating economic projection errors to predicted air pollutant emission errors. On the basis of the OBE report's nationwide projections to 1970, the error in projected gross national product was just under 6%, the error in the projected population was 0.75%. The significance of these errors with respect to projected emissions is unkown.

The National Source Inventory Section of EPA processes and publishes data on point and area source emissions of air pollutants, and is responsible for determining the quality of the data used. The emissions inventory is a basic requirement of states' implementation plans and provides EPA with a valuable management tool in the decision-making process associated with the administration of air pollution control activity. *It is no longer satisfactory to merely provide an inventory; it is necessary to quantitatively state in statistical terms error existent in a specified inventory*. This being the case, the National Source Inventory Section actively sought development of statistical methodology to establish the quality of emissions data.

The methods of weighted sensitivity analysis were chosen as the most flexible approach to develop the necessary techniques, and the Federal Systems Center of IBM Corporation was engaged to perform the necessary theoretical and numerical analyses, as well as to develop the necessary software and its documentation.

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PROJECT OBJECTIVES

It is appropriate to summarize at the outset the objectives sought in undertaking the project, as mutually agreed upon between EPA and IBM. The goals to be achieved in the project, as stated in the work scope, were as follows:

1. Analysis

   In this activity, a methodology is to be formally derived whereby accuracy requirements of component parts of an emission inventory can be calculated so as to insure an overall acceptable accuracy in the total inventory. The techniques of weighted sensitivity analysis are to be applied in the performance of this task.

2. Program Development

   In this activity, a FORTRAN computer program for weighted sensitivity analysis is to be designed, coded, tested and debugged. The resulting software will provide a means to evaluate the maximum permissible errors in emissions data with sufficient flexibility to be applicable to both source categories and geographical areas, for a given maximum permissible error of the nationwide inventory. Complete compatibility with NEDS will be assured.

3. Numerical Validation

   In order to demonstrate the adequacy of the analysis and the usage of the computer program, three sample analyses shall be performed (using 1970 nationwide emissions data) to indicate the maximum error in source categories and subcategories (nationwide) for three different nationwide inventory maximum errors to be provided by EPA.

0221

SUMMARY OF RESULTS

Project objectives and requirements as set forth above have been fully achieved. Furthermore, significant developments in both analysis and programming beyond the original goals have been accomplished. A summary of the addtional results obtained is as follows:

1. Refinement of the theoretical weighted sensitivity analysis to distribute both percentage and physical errors in emissions according to their respective weightings.
2. Extension of the analysis to cover the case where one or more of the error components in a given level are to be fixed by the analyst.
3. Modification and/or extension of the software to implement developments 1 and 2 as part of the deliverable program.
4. Parameterization of the software to allow the analyst to apply the program to alternative hierarchial configurations of the emissions data.
5. Extension of the software to permit application of the weighted sensitivity analysis to emissions data at the SCC level of aggregation.
6. Preparation of a comprehensive set of numerical analyses to demonstrate applicability of the technique and adequacy of the computer program. Numerical analyses were conducted for different areas (e.g., county, state, AQCR, U.S.), for different emissions data configurations (e.g., point and area fuel combustion emissions restructured by fuel usage).
7. Consolidated application of weighted sensitivity analysis techniques and Chebyshev's inequality to establish confidence levels for emission inventories.

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Section II

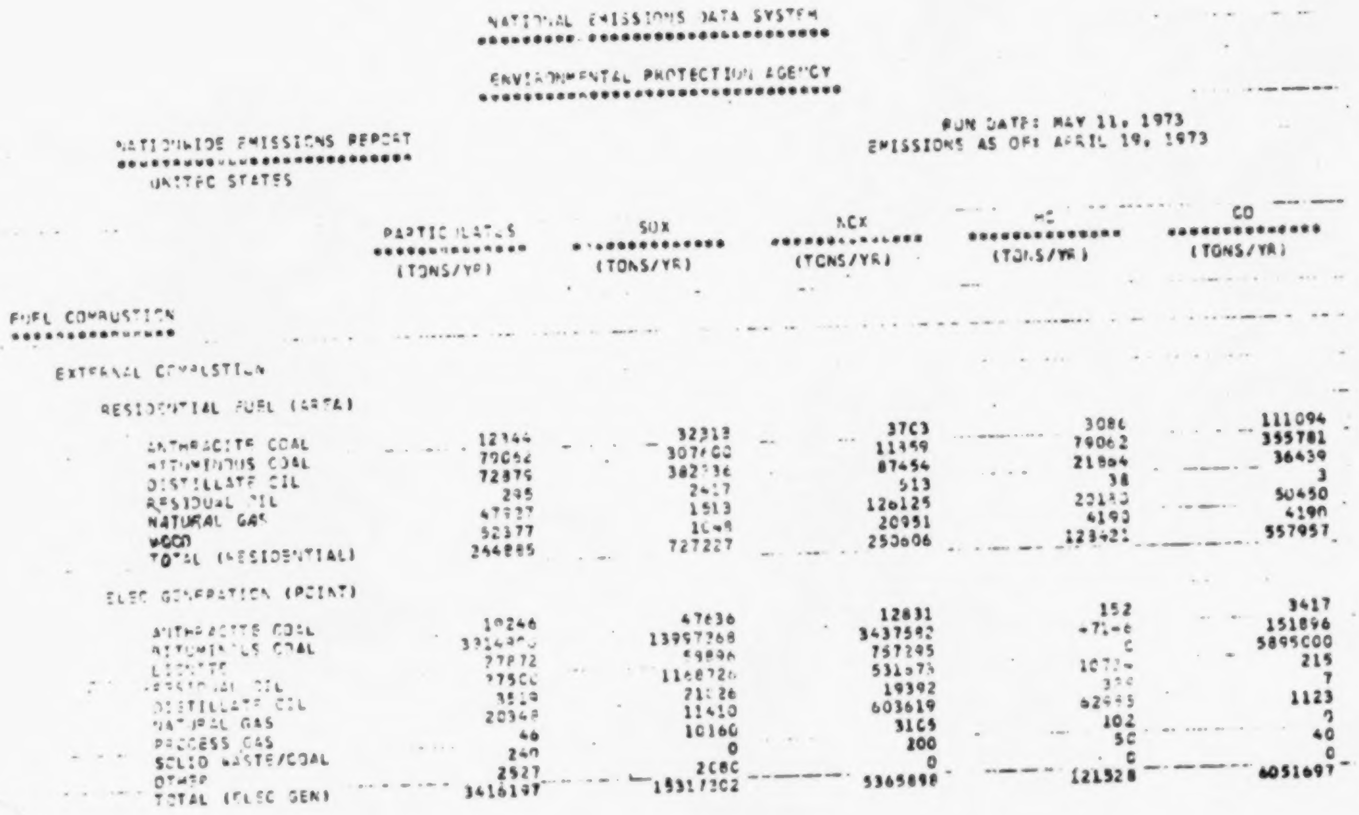
GENERAL ANALYSIS

The section presents the techniques developed for weighted sensitivity analysis and its application to emissions data as contained in the National Emissions Data System (NEDS) reports. The presentation will be focused on the application of the analytical technique to emissions data, rather than the theoretical development of the technique itself. The reader interested in the latter is referred to Appendix A for a full discussion of the theoretical analysis. An annotated numerical example is also included in this section, to provide insight on how the propagation of random error throughout the inventory is accounted for in the application of the weighted error formulae.

HIERARCHIAL STRUCTURE OF EMISSIONS DATA

The reports of the National Emissions Data System (NEDS) constitute the primary source of data for this project. In fact, the weighted sensitivity analysis technique introduced below was specifically developed for the treatment of random error in these sets of data, although it can also be applied to any other set of data processing the same properties.

Figure 2.1 displays a sample nationwide emissions report from NEDS. Emissions as of April 19, 1973, are listed by source categories for five classes of air pollutants: particulates, sulfur oxides, nitrogen oxides, hydrocarbons and carbon monoxide. The source categorization is uniform for other area reports, i.e., county, AQCR, and state emissions reports.



```
                               NATIONAL EMISSIONS DATA SYSTEM
                               ***************************

                               ENVIRONMENTAL PROTECTION AGENCY
                               ***************************

                                                                 RUN DATE: MAY 11, 1973
    NATIONWIDE EMISSIONS REPORT                              EMISSIONS AS OF: APRIL 19, 1973
    ***************************
       UNITED STATES

                               PARTICULATES       SOX            NOX            HC             CO
                               ************  ************   ************   ************   ************
                                (TONS/YR)      (TONS/YR)      (TONS/YR)      (TONS/YR)      (TONS/YR)

FUEL COMBUSTION
***************

   EXTERNAL COMBUSTION

      RESIDENTIAL FUEL (AREA)

         ANTHRACITE COAL             12344          32312           3703           3086         111094
         BITUMINOUS COAL             79054         307600          11359          79062         355781
         DISTILLATE OIL              72875         382336          87454          21864          36439
         RESIDUAL OIL                  295           2417            513             38              3
         NATURAL GAS                 47927           1513         126125          20183          50450
         WOOD                        52377           1049          20951           4193           4190
         TOTAL (RESIDENTIAL)        264885         727227         250606         123421         557957

      ELEC GENERATION (POINT)

         ANTHRACITE COAL             10246          47636          12831            152           3417
         BITUMINOUS COAL       [illegible]       13957368        3437592    [illegible]         151896
         LIGNITE                     27872          98896         757295              0        5895000
         RESIDUAL OIL                27500        1168726         531573 1072[illegible]            215
         DISTILLATE OIL               3519          21126          19392  3[illegible]              7
         NATURAL GAS                 20348          11410         603619          62945           1123
         PROCESS GAS                    46          10160           3165            102              0
         SOLID WASTE/COAL              240              0            200             50             40
         OTHER                        2527           2080              0              0              0
         TOTAL (ELEC GEN)          3416197       15317302        5365898         121528        6051697
```

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Figure 2.1 NEDS Data in Tabular Format

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ANTHRACITE COAL					
POINT SOURCES	10096	25078	6151	96	1745
BITUMINOUS COAL					
AREA SOURCES	[illegible]	903767	175953	11730	23460
POINT SOURCES	[illegible]	2644058	582521	17266	53929
RESIDUAL OIL					
AREA SOURCES	13156	48799	52623	2631	175
POINT SOURCES	54042	759396	166784	3934	635
DISTILLATE OIL					
AREA SOURCES	14591	247475	63994	3201	213
POINT SOURCES	23939	34578	103645	4942	329
NATURAL GAS					
AREA SOURCES	[illegible]	743	222916	44519	495
POINT SOURCES	[illegible]	30178	1483014	170225	4634
PROCESS GAS					
AREA SOURCES	5	0	71	12	0
POINT SOURCES	[illegible]	94790	6295	58	2
COKE					
POINT SOURCES	1143	1706	0	2	0
WOOD					
AREA SOURCES	1460	29	584	117	117
POINT SOURCES	147086	9695	97072	22104	19487
LIQUID PETROL GAS					
POINT SOURCES	256	24	1703	561	1
OTHER					
POINT SOURCES	5066	3341	237	29	7723
TOTAL (INDUSTRIAL)					
AREA SOURCES	1412216	1200813	516042	67205	24461
POINT SOURCES	1562142	3601456	2449426	223016	88455
COMM-INSTITUTIONAL FUEL					
ANTHRACITE COAL					
AREA SOURCES	504	551	221	4	133
POINT SOURCES	236	1391	86	2	114
BITUMINOUS COAL					
AREA SOURCES	144322	221777	26351	5728	20623
POINT SOURCES	53973	86857	17330	1657	4882
RESIDUAL OIL					
AREA SOURCES	51482	596181	134300	6715	448
POINT SOURCES	7730	90474	20031	954	84
DISTILLATE OIL					
AREA SOURCES	60961	217820	243443	12172	811
POINT SOURCES	743	4255	2611	132	10
NATURAL GAS					
AREA SOURCES	17737	560	93352	7468	15670
POINT SOURCES	20888	2965	124134	8575	20585
WOOD					
AREA SOURCES	102	2	41	8	8
POINT SOURCES	586	49	625	140	125
LIQUID PETROL GAS					
POINT SOURCES	2	0	10	1	2
TOTAL (COMM-INST)					
AREA SOURCES	275009	1036922	497708	32096	40693
POINT SOURCES	97158	176071	164927	11461	25803
OTHERS (POINT)	2741	211	246	0	0
TOTAL (EXTERNAL COMB)					
AREA SOURCES	1952109	2964961	1264356	227722	622171
POINT SOURCES	[illegible]	19095039	7980357	356005	[illegible]

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Figure 2.1 (cont)

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INTERNAL COMBUSTION (POINT)					
ELECTRIC GENERATION					
DISTILLATE OIL	1043	2371	6287	62	92
NATURAL GAS	13	[illegible]	5523	0	0
DIESEL	94	196	2687	269	1634
TOTAL (ELEC GEN)	1151	2567	14498	331	1726
INDUSTRIAL FUEL					
DISTILLATE OIL	86	468	920	35	212
NATURAL GAS	1265	7295	828953	27637	10423
GASOLINE	9	4	168	491	1228
DIESEL FUEL	48	87	1245	128	729
TOTAL (INDUSTRIAL)	1429	7799	831285	28291	12592
COMM-INSTITUTIONAL					
DIESEL	47	97	1328	133	808
OTHER	6	2	11	9	3
TOTAL (COMM-INST)	53	99	1339	142	811
ENGINE-TESTING					
AIRCRAFT	172	72	397	377	940
OTHER	151	0	0	0	0
TOTAL (ENG TESTNG)	323	72	397	377	940
OTHER (POINT)	0	0	0	220	0
TOTAL (INTERNAL COMB)	2956	10537	847519	29360	16069
TOTAL (FUEL COMBUSTION)					
AREA SOURCES	1952149	2964961	1264356	227722	623111
POINT SOURCES	5073194	19105576	8827916	385365	6182023
INDUSTRIAL PROCESS (POINT) **************************					
CHEMICAL MANUFACTURING	194243	431773	91649	2151455	5799504
FOOD/AGRICULTURAL	215492	912	2989	22255	548
PRIMARY METAL	1476560	3792555	15060	111779	2980138
SECONDARY METALS	144426	89535	1776	2264	1393596
MINERAL PRODUCTS	4589503	305369	99161	7559	18723
PETROLEUM INDUSTRY	1432023	1832762	3020727	865146	7254689
WOOD PRODUCTS	323630	81233	2230	12764	527647
EVAPORATION	881	2545	545	1598193	2110
METAL FABRICATION	4035	2266	905	1002	38
LEATHER PRODUCTS	0	0	0	380	0
TEXTILE MANUFACTURING	801	40	0	4778	0
INPROCESS FUEL	20592	30513	16618	12479	4881
OTHER/NOT CLASSIFIED	8364	10908	433	93637	30860
TOTAL (INDUSTRIAL)	8410250	6580464	3252095	4883692	18012733

Figure 2.1 (cont.)

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SOLID WASTE DISPOSAL					
GOVERNMENT (POINT)					
MUNICIPAL INCINERATION	34613	5323	4268	12453	64403
OPEN BURNING	24035	1597	9503	49278	137447
TOTAL (GOVERNMENT)	58658	6926	13771	61731	201669
RESIDENTIAL (AREA)					
ON SITE INCINERATION	179425	2930	5981	598064	1794192
OPEN BURNING	114900	7242	43090	244174	610436
TOTAL (RESIDENTIAL)	294325	10172	49071	842238	2404628
COMMERCIAL-INSTITUTIONAL					
ON SITE INCINERATION					
AREA SOURCES	31945	3994	5325	36024	53248
POINT SOURCES	1253	761	544	1341	10989
OPEN BURNING					
AREA SOURCES	38554	2410	14458	61726	204820
POINT SOURCES	1154	0	136	273	3409
APARTMENT					
POINT SOURCES	1164	19	116	552	740
TOTAL (COMM-INST)					
AREA SOURCES	70533	6403	19783	105552	258068
POINT SOURCES	3527	779	786	2166	15138
INDUSTRIAL					
ON SITE INCINERATION					
AREA SOURCES	147877	18495	24546	123230	246461
POINT SOURCES	62751	17945	7786	55589	587646
OPEN BURNING					
AREA SOURCES	104570	6536	39214	222212	555530
POINT SOURCES	14246	255	2766	34923	48957
AUTO BODY INCINERATION					
POINT SOURCES	14	0	1	3	17
OTHER					
POINT SOURCES	38	3150	8	79	22
TOTAL (INDUSTRIAL)					
AREA SOURCES	252447	25020	63860	345443	801991
POINT SOURCES	77049	21350	10562	90594	636643
OTHER (POINT)	7	0	0	0	0
TOTAL (SOLID WASTE DISP)					
AREA SOURCES	617275	41595	132713	1296233	3464687
POINT SOURCES	141280	29049	25119	153482	853650

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Figure 2.1 (cont.)

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```
TRANSPORTATION (AREA)
*********************

  LAND VEHICLES

    GASOLINE

      LIGHT VEHICLES               344770      206862     4941698    10522889    57097621
      HEAVY VEHICLES                20573       12344      685779     1397178     5754393
      OFF HIGHWAY                   11900        7437      361797      822577     4507067
      TOTAL (GASOLINE)             377243      226643     5989274    12742645    67359081

    DIESEL

      HEAVY VEHICLES                40210       80421     1139292      113929      670172
      OFF HIGHWAY                   15494       32180      440984       44098      268166
      RAIL                          52197      135712      156591      104394      146151
      TOTAL (DIESEL)               107901      248312     1736867      262421     1084489

  AIRCRAFT

    MILITARY                       147475       28161       70847      343120      368317
    CIVIL                            8438        1676        7622       37369      213538
    COMMERCIAL                      55226       12235       34551      132542      314362
    TOTAL (AIRCRAFT)               211138       42071      113021      513031      896217

  VESSELS

    BITUMINOUS COAL                  1273        3183         191        1273        5729
    DIESEL FUEL                     13667       35535       41002       27334       38268
    RESIDUAL OIL                     6036       26242       15745         787          52
    GASOLINE                          823         514       18095       56858      311523
    TOTAL (VESSELS)                 21799       65474       75033       86252      355573

  GAS HANDLING EVAP LOSS                0           0           0      913379           0

  TOTAL (TRANSPORTATION)           718081      582501     7914195    14517727    69695361

MISCELLANEOUS (AREA)
********************

  SLASH BURNING                    220278           0       25915      259150      777451
  SOLVENT EVAPORATION LOSS              0           0           0     1383855           0
  TOTAL (MISCELLANEOUS)            220278           0       25915     1643005      777451

OTHER (POINT)                           0           0           0           0           0
*************

GRAND TOTAL
***********

  AREA SOURCES                    3507743     3589057     9237179    17684687    74560610
  POINT SOURCES                  13624732    25715089    12105130     5422538    25048407
  TOTAL                          17132475    29304146    21342309    23107225    99609017
```

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Figure 2.1 (cont.)

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From the viewpoint of analysis, the most important property of these sets of data is their hierarchial nature. In fact, the tabular source categorization of the NEDS reports can be best understood if its hierarchial structure is explicitly recognized. This can be effectively done by converting the tabular format of Figure 2.1 to a tree format, as shown in Figure 2-2. Taking the grand total of the very bottom of the table in Figure 2.1 as the starting point or highest level, the tree unfolds back hierarchially through four and sometimes five successively lower levels of aggregation, the lowest level being the elementary emissions data for each segment of the tree.

The tree format of Figure 2.2 provides a convenient, systematic representation of an emissions inventory for analysis purposes. Each node of the tree, together with the branches coming out of it, constitutes a level of error propagation in the inventory. Therefore, the weighted sensitivity analysis must be applied hierarchially, starting with the allowable error for the grand total (i.e., the overall allowable error), so as to compute allowable errors for each one of the branches which, if satisfied, insure that the overall allowable error is not exceeded.

Figure 2.2 displays the tree of source nodes and branches, numerically annotated to facilitate the discussion. Thus, for example, node 1.1 (fuel combustion-point) has two branches denoted as 1.1.1 and 1.1.2 (external combustion and internal combustion, respectively). The emission quantity (in tons/year) associated with each branch throughout the tree is of course read from the appropriate total, subtotal or elementary data item in the NEDS table of Figure 2.1. This is illustrated in Figure 2.3, which displays a segment of the tree with the actual particulate emission quantities for each branch. For example, 3416197 tons/year of particualte emissions is shown as originating from electricity generation through external fuel

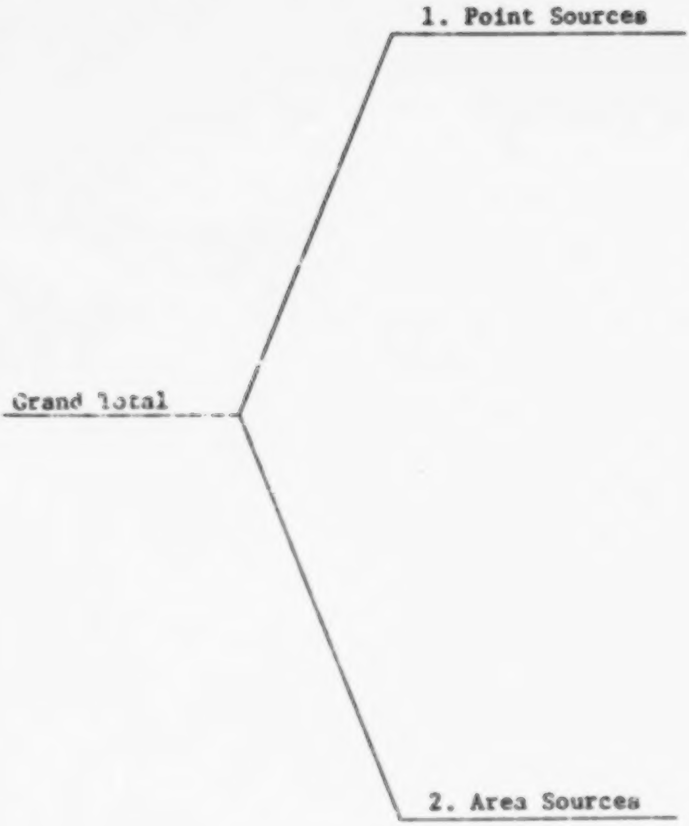
1. Point Sources
Grand Total
2. Area Sources

Figure 2.2 NEDS source categories in tree format

0 030

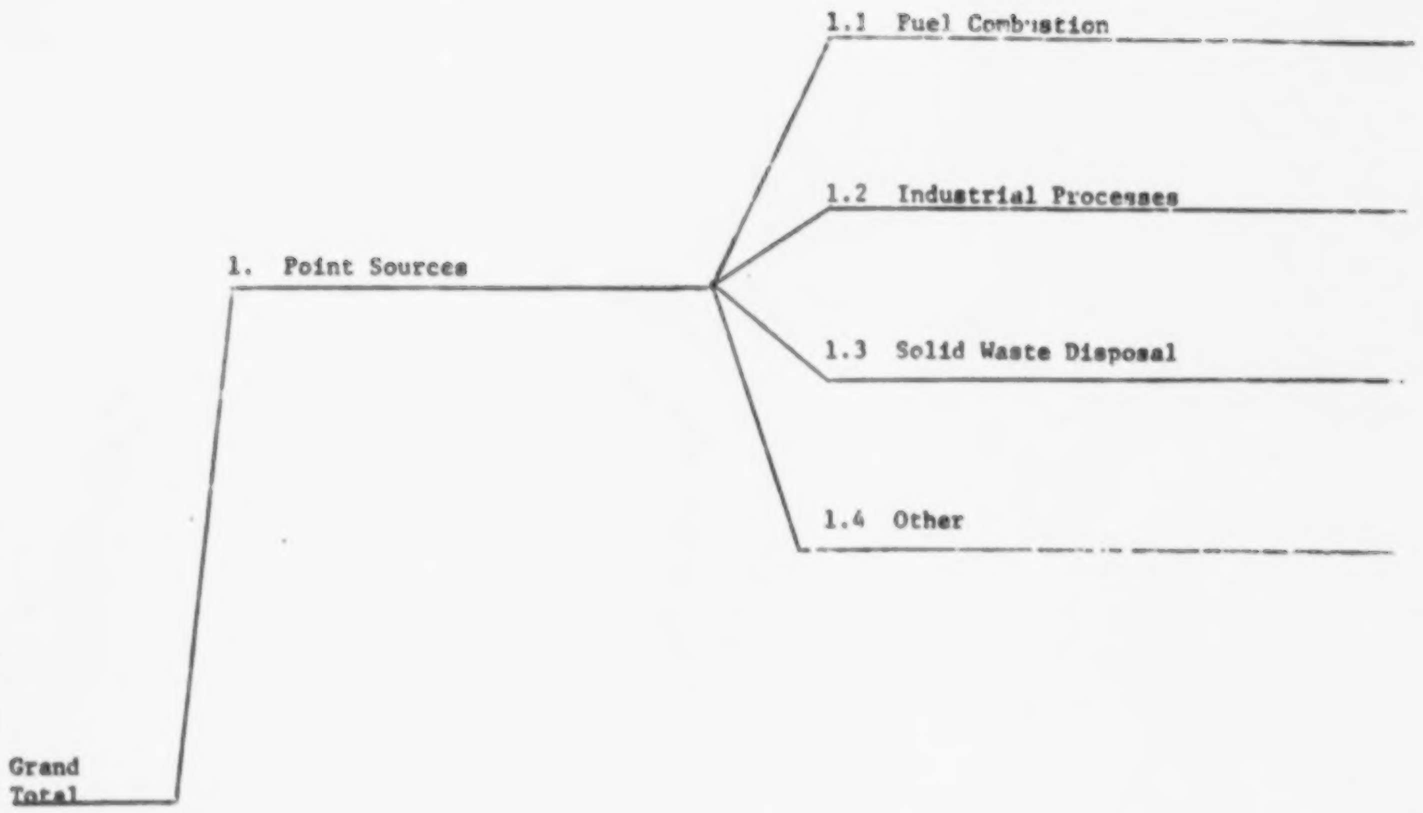
Grand Total
1. Point Sources
1.1 Fuel Combustion
1.2 Industrial Processes
1.3 Solid Waste Disposal
1.4 Other

Figure 2.2 (cont.)

0-031

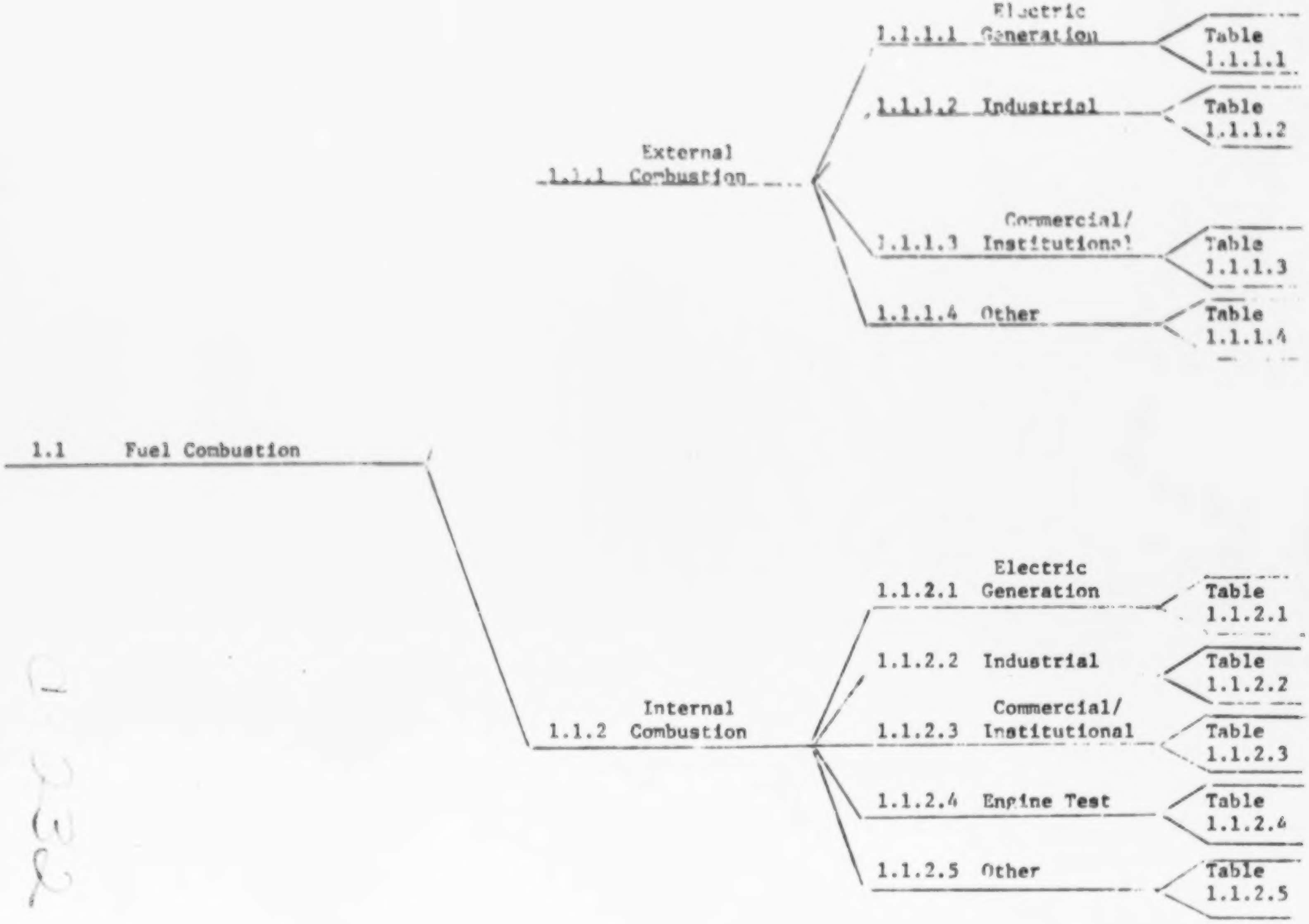
1.1 Fuel Combustion
1.1.1 External Combustion
1.1.1.1 Electric Generation
Table 1.1.1.1
1.1.1.2 Industrial
Table 1.1.1.2
1.1.1.3 Commercial/ Institutional
Table 1.1.1.3
1.1.1.4 Other
Table 1.1.1.4
1.1.2 Internal Combustion
1.1.2.1 Electric Generation
Table 1.1.2.1
1.1.2.2 Industrial
Table 1.1.2.2
1.1.2.3 Commercial/ Institutional
Table 1.1.2.3
1.1.2.4 Engine Test
Table 1.1.2.4
1.1.2.5 Other
Table 1.1.2.5

Figure 2.2 (cont.)

TABLE 1.1.1.1

Anthracite Coal	1.1.1.1.1
Bituminous Coal	.2
Lignite	.3
Residual Oil	.4
Distillate Oil	.5
Natural Gas	.6
Process Gas	.7
Coke	.8
Bagasse	.9
Solid Waste/Coal	.10
Other	.11

TABLE 1.1.1.2

Anthracite Coal	1.1.1.2.1
Bituminous Coal	.2
Lignite	.3
Residual Oil	.4
Distillate Oil	.5
Natural Gas	.6
Process Gas	.7
Coke	.8
Wood	.9
Liquid Petrol Gas	.10
Bagasse	.11
Other	.12

TABLE 1.1.1.3

Anthracite Coal	1.1.1.3.1
Bituminous Coal	.2
Lignite	.3
Residual Oil	.4
Distillate Oil	.5
Natural Gas	.6
Wood	.7
Liquid Petrol Gas	.8
Other	.9

TABLE 1.1.2.1

Distillate Oil	1.1.2.1.1
Natural Gas	.2
Diesel	.3
Other	.4

TABLE 1.1.2.2

Distillate Oil	1.1.2.2.1
Natural Gas	.2
Gasoline	.3
Diesel Fuel	.4
Other	.5

Figure 2.2 (cont.)

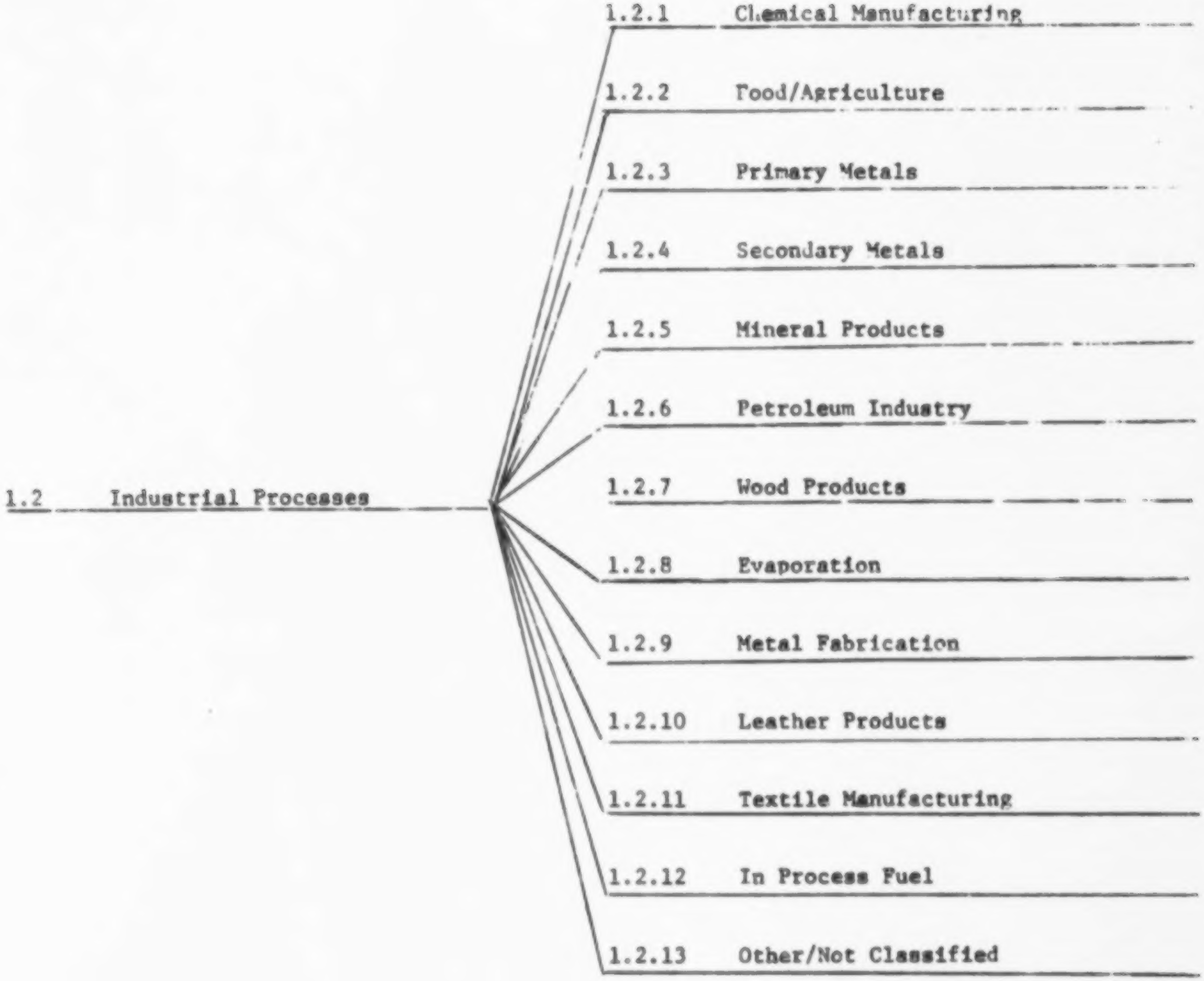
1.2 Industrial Processes
1.2.1 Chemical Manufacturing
1.2.2 Food/Agriculture
1.2.3 Primary Metals
1.2.4 Secondary Metals
1.2.5 Mineral Products
1.2.6 Petroleum Industry
1.2.7 Wood Products
1.2.8 Evaporation
1.2.9 Metal Fabrication
1.2.10 Leather Products
1.2.11 Textile Manufacturing
1.2.12 In Process Fuel
1.2.13 Other/Not Classified

Figure 2.2 (cont.)

0234

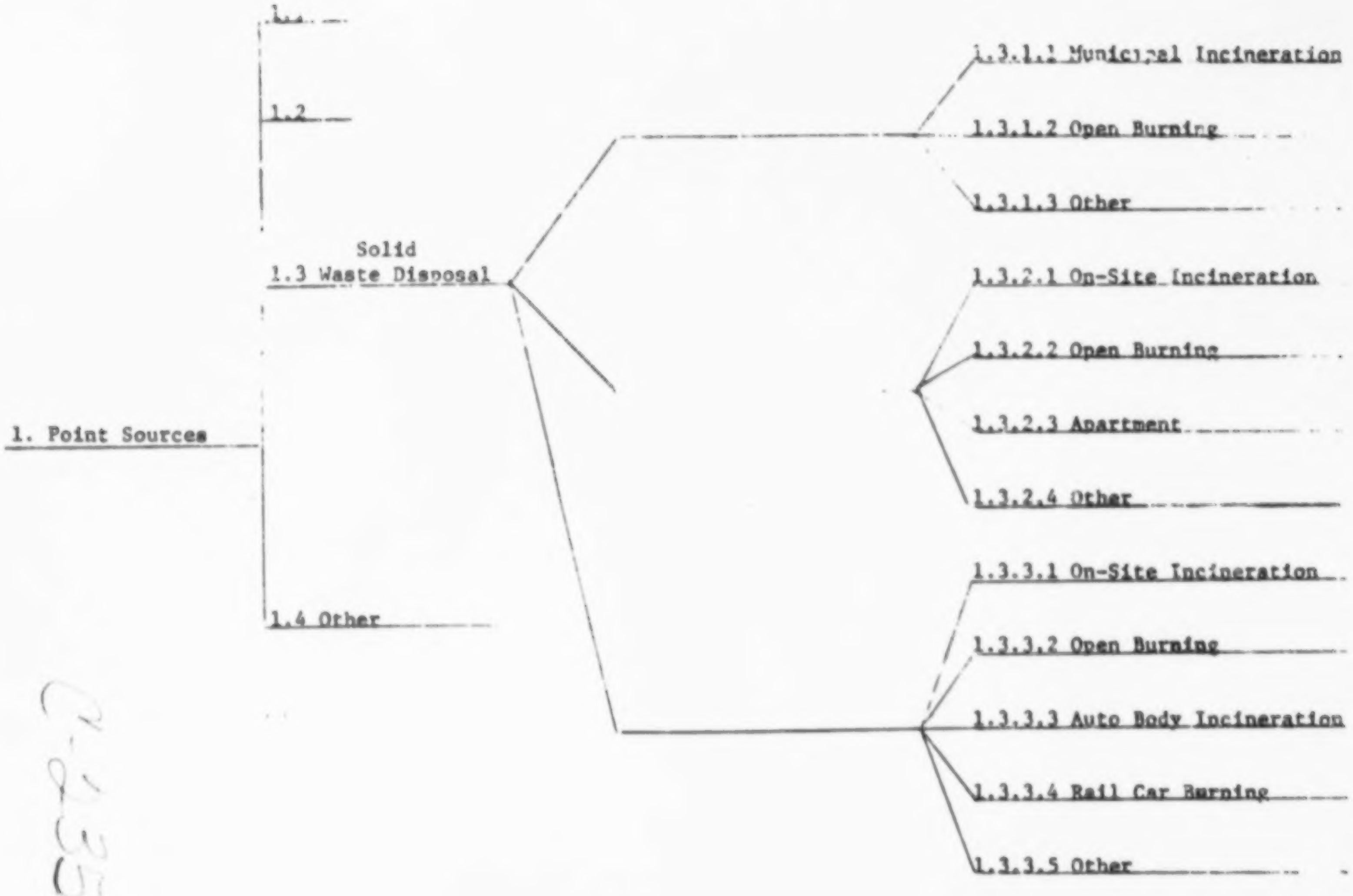
1.1
1.2
Solid
1.3 Waste Disposal
1.4 Other
1. Point Sources
1.3.1.1 Municipal Incineration
1.3.1.2 Open Burning
1.3.1.3 Other
1.3.2.1 On-Site Incineration
1.3.2.2 Open Burning
1.3.2.3 Apartment
1.3.2.4 Other
1.3.3.1 On-Site Incineration
1.3.3.2 Open Burning
1.3.3.3 Auto Body Incineration
1.3.3.4 Rail Car Burning
1.3.3.5 Other

Figure 2.2 (cont.)

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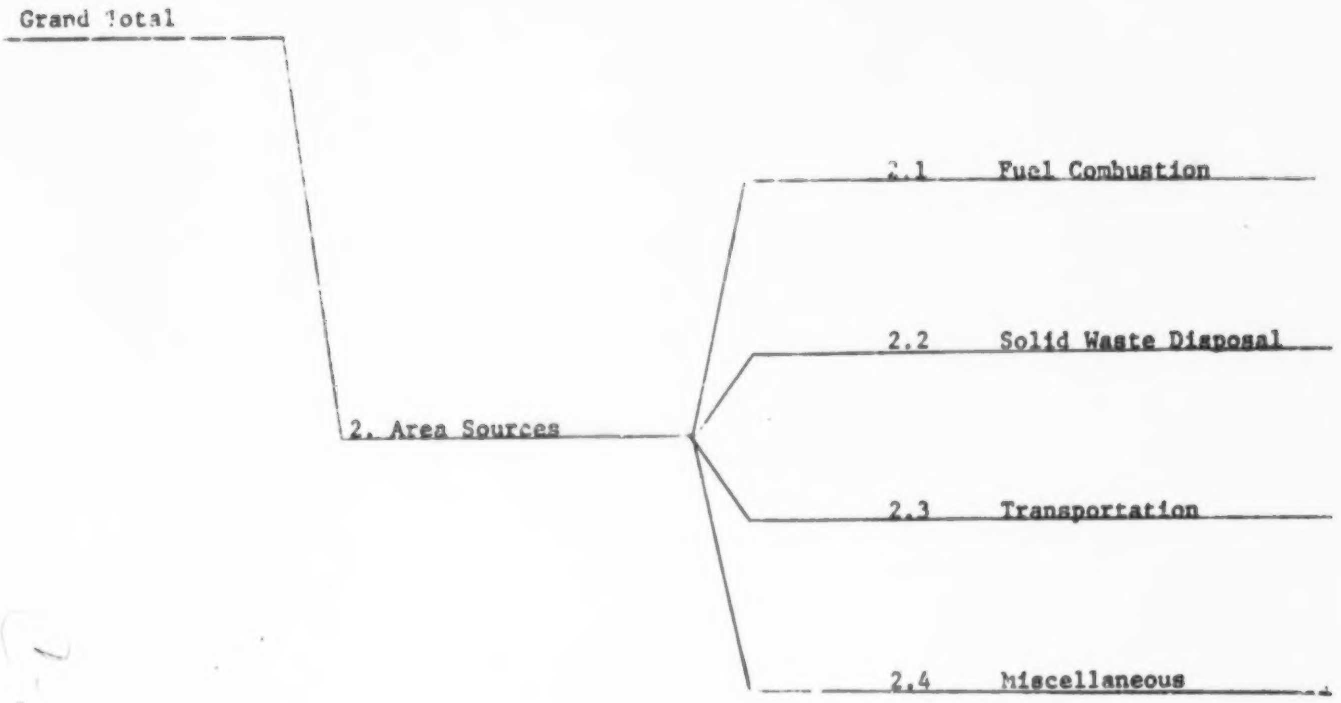
Grand Total
2. Area Sources
2.1 Fuel Combustion
2.2 Solid Waste Disposal
2.3 Transportation
2.4 Miscellaneous

Figure 2.2 (cont.)

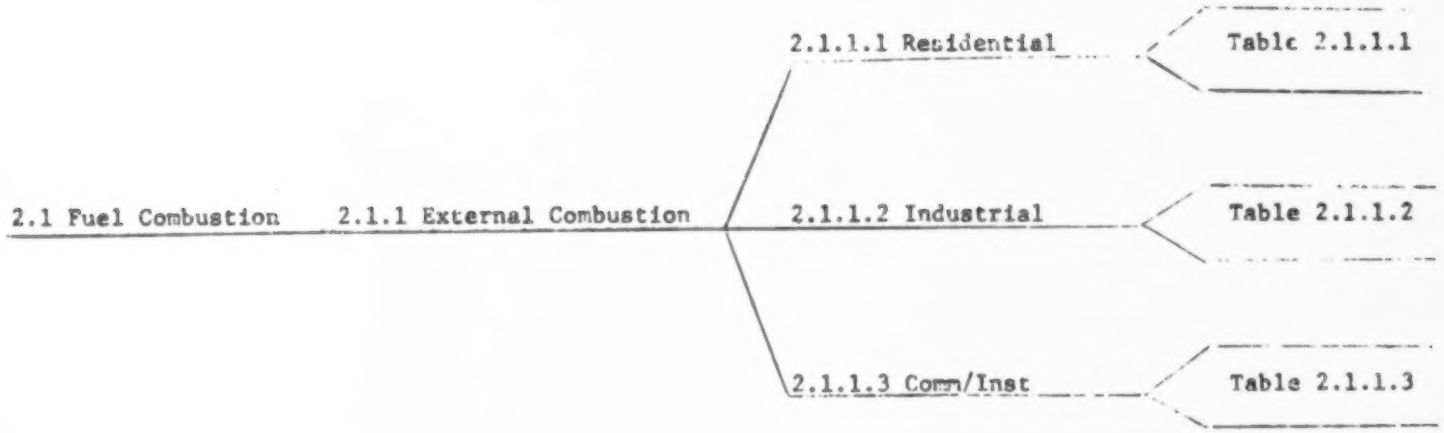
2.1 Fuel Combustion
2.1.1 External Combustion
2.1.1.1 Residential
2.1.1.2 Industrial
2.1.1.3 Comm/Inst
Table 2.1.1.1
Table 2.1.1.2
Table 2.1.1.3

Figure 2.2 (cont.)

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TABLE 2.1.1.1

Anthracite Coal	2.1.1.1.1
Bituminous Coal	2.1.1.1.2
Distillate Oil	2.1.1.1.3
Residual Oil	2.1.1.1.4
Natural Gas	2.1.1.1.5
Wood	2.1.1.1.6

TABLE 2.1.1.2

Anthracite Coal	2.1.1.2.1
Bituminous Coal	2.1.1.2.2
Residual Oil	2.1.1.2.3
Distillate Oil	2.1.1.2.4
Natural Gas	2.1.1.2.5
Process Gas	2.1.1.2.6
Coke	2.1.1.2.7
Wood	2.1.1.2.8

TABLE 2.1.1.3

Anthracite Coal	2.1.1.3.1
Bituminous Coal	2.1.1.3.2
Residual Oil	2.1.1.3.3
Distillate Oil	2.1.1.3.4
Natural Gas	2.1.1.3.5
Wood	2.1.1.3.6

Figure 2.2 (cont.)

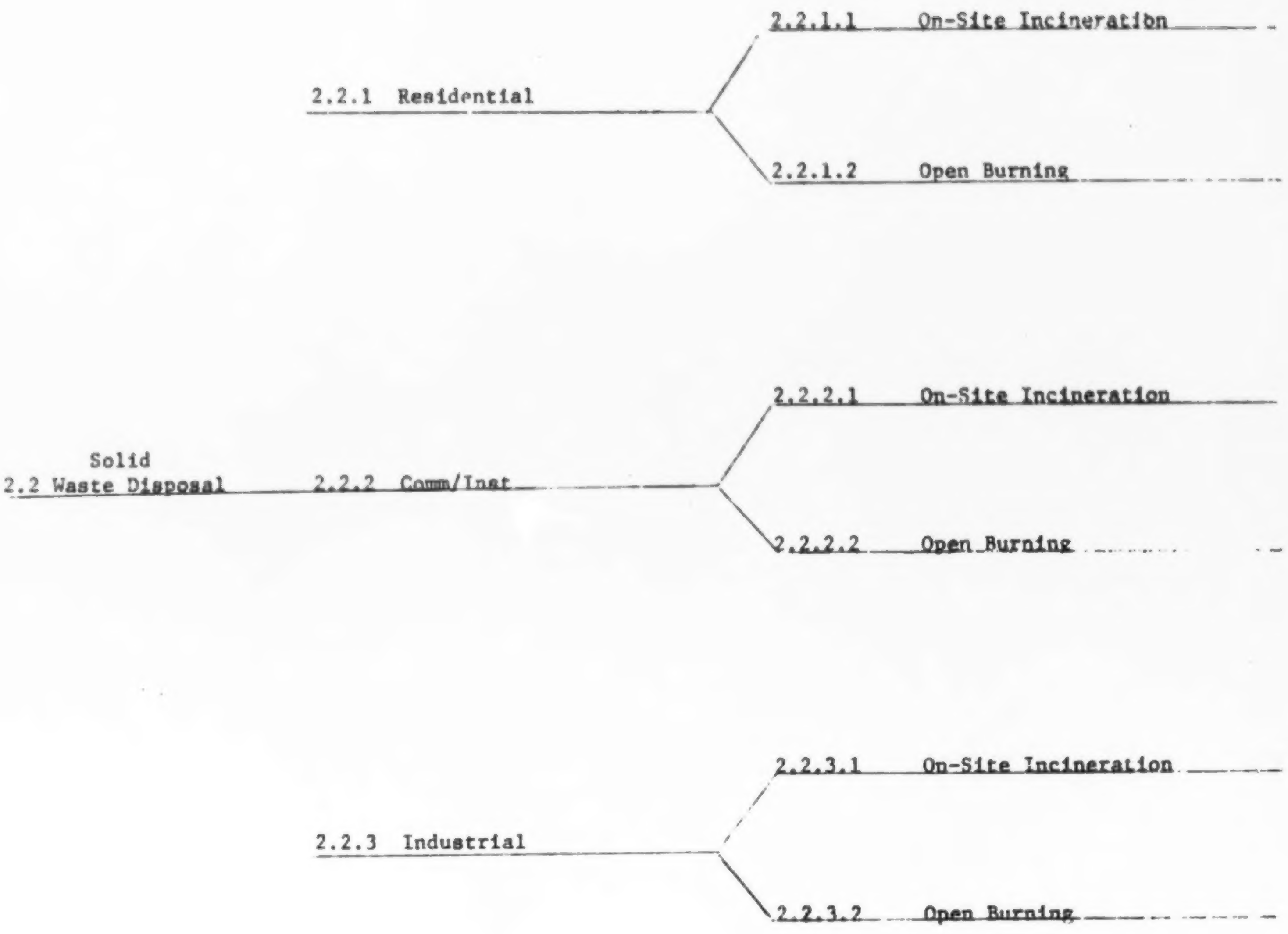
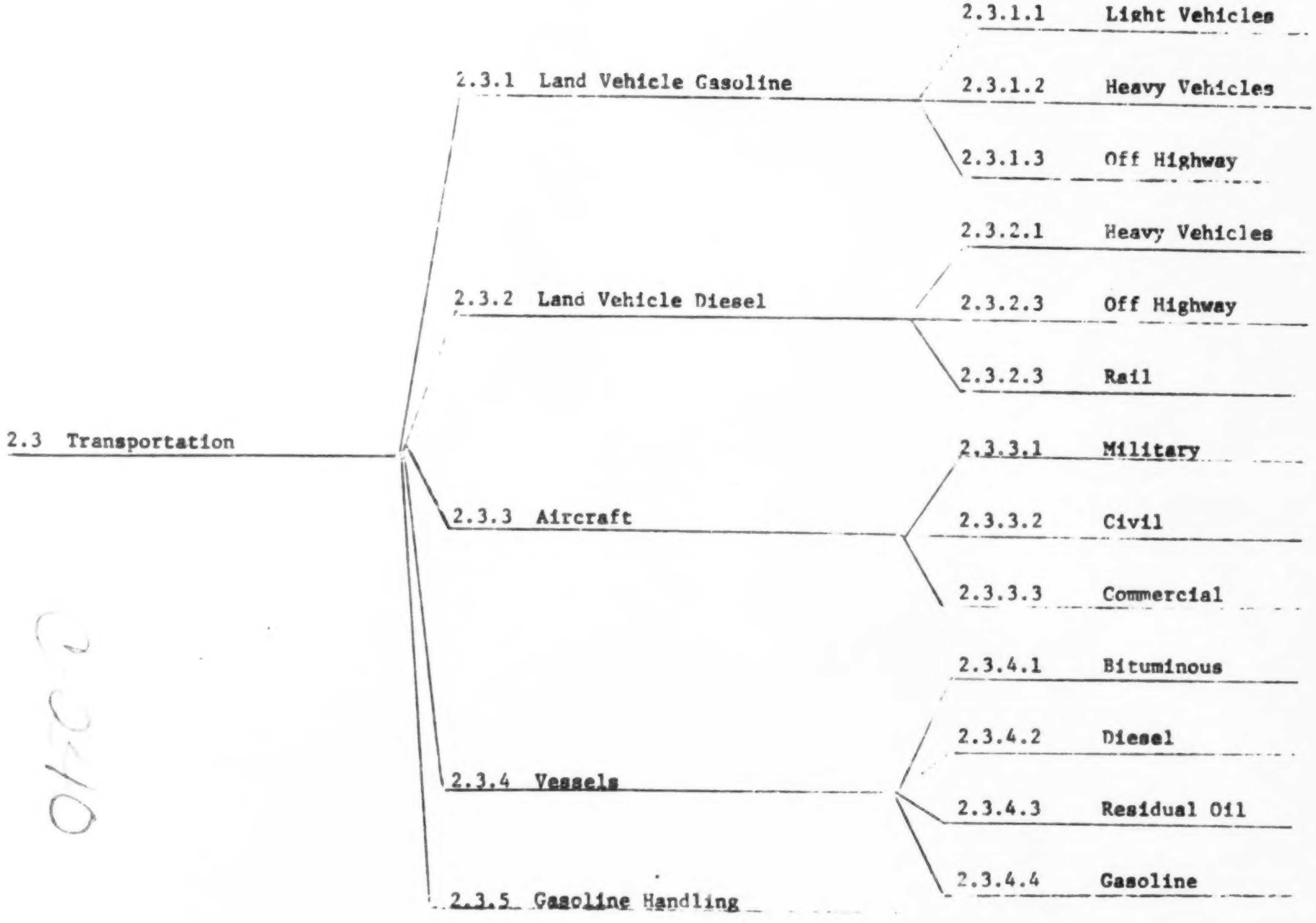

Solid
2.2 Waste Disposal
2.2.1 Residential
2.2.1.1 On-Site Incineration
2.2.1.2 Open Burning
2.2.2 Comm/Inst
2.2.2.1 On-Site Incineration
2.2.2.2 Open Burning
2.2.3 Industrial
2.2.3.1 On-Site Incineration
2.2.3.2 Open Burning

Figure 2.2 (cont.)

L-039


2.3 Transportation
2.3.1 Land Vehicle Gasoline
2.3.1.1 Light Vehicles
2.3.1.2 Heavy Vehicles
2.3.1.3 Off Highway
2.3.2 Land Vehicle Diesel
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2.3.4.3 Residual Oil
2.3.4.4 Gasoline
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Figure 2.2 (cont.)

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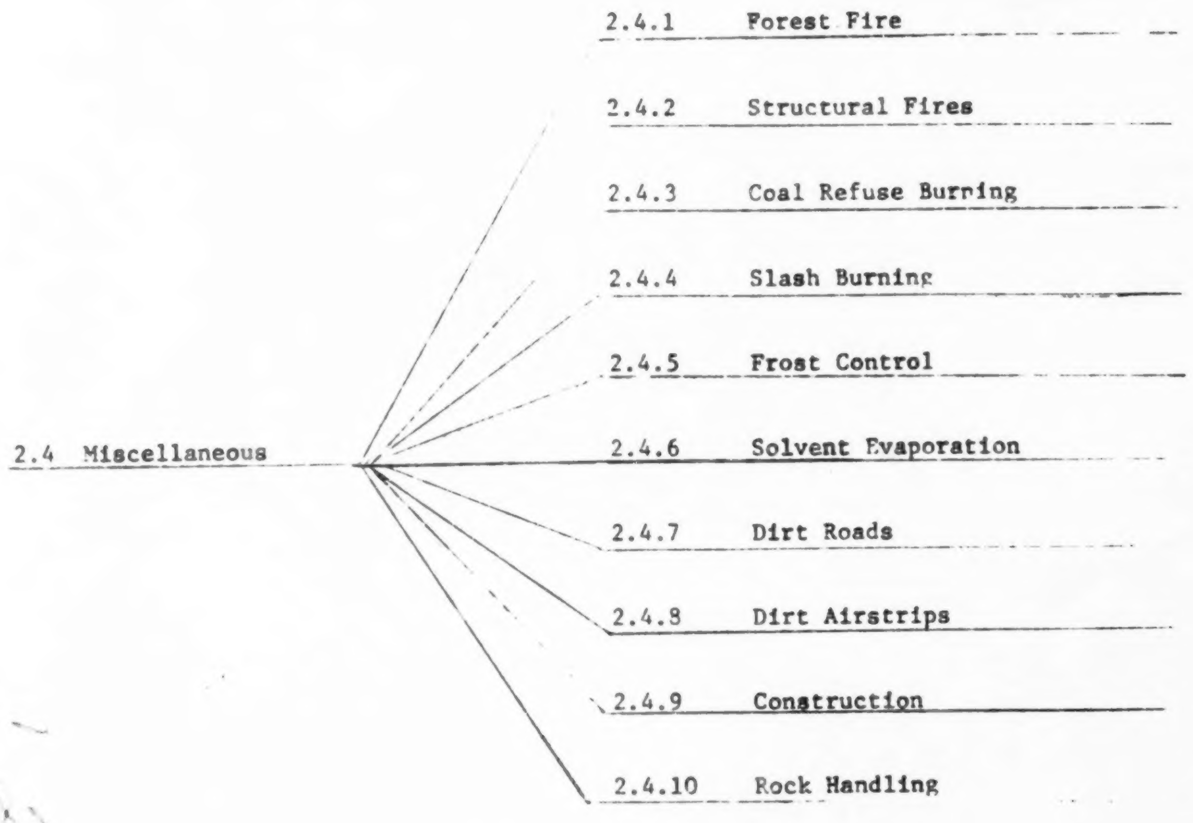
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2.4.1 Forest Fire
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Figure 2,2 (cont.)

combustion at point sources. Observe that the summation of the emissions associated with their node. This relationship will be the basis for the weightings to be used below in computing allowable errors for each branch of the tree.

WEIGHTED SENSITIVITY ANALYSIS

In this project, the mathematics of sensitivity analysis were directed to the development of accuracy requirements for the component parts of an emissions inventory such that a given accuracy requirement for the overall inventory is satisfied. The objective of sensitivity analysis is to determine the effect (changes) on some measure of performance due to changes in each component that makes up the measure of performance. In the simplest case the measure of performance is the sum of component measures. In the case of an emissions inventory, it was shown above that the total emissions for a given source class is always equal to the sum of the emissions from the source subclasses in that class. Furthermore, since each one of these emissions have been independently measured, it follows that the overall squared error for the source class is a linear function of the squared errors of the source subclasses.

This analysis is based on statistical linear models and their application to represent propagation of error in sets of data (References 1,2,5). For clarity of presentation, the discussion in this subsection will be focused on the main analytical results, their statistical interpretation, and their practical implications. Detailed mathematical derivations of all formulae are given in Appendix A.

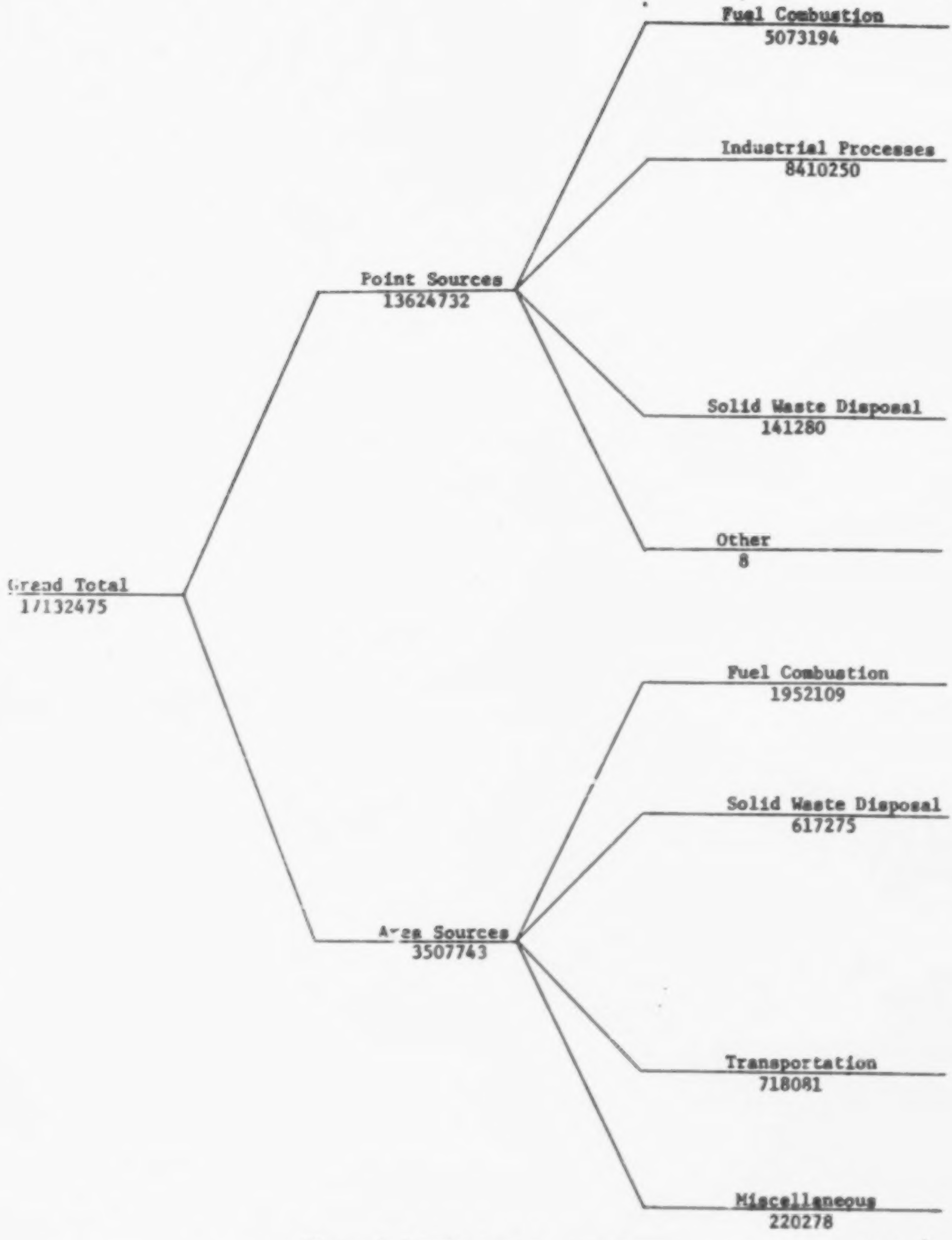
Fuel Combustion
5073194
Industrial Processes
8410250
Point Sources
13624732
Solid Waste Disposal
141280
Other
8
Grand Total
17132475
Fuel Combustion
1952109
Solid Waste Disposal
617275
Area Sources
3507743
Transportation
718081
Miscellaneous
220278

Figure 2.3 NEDS data in tree format

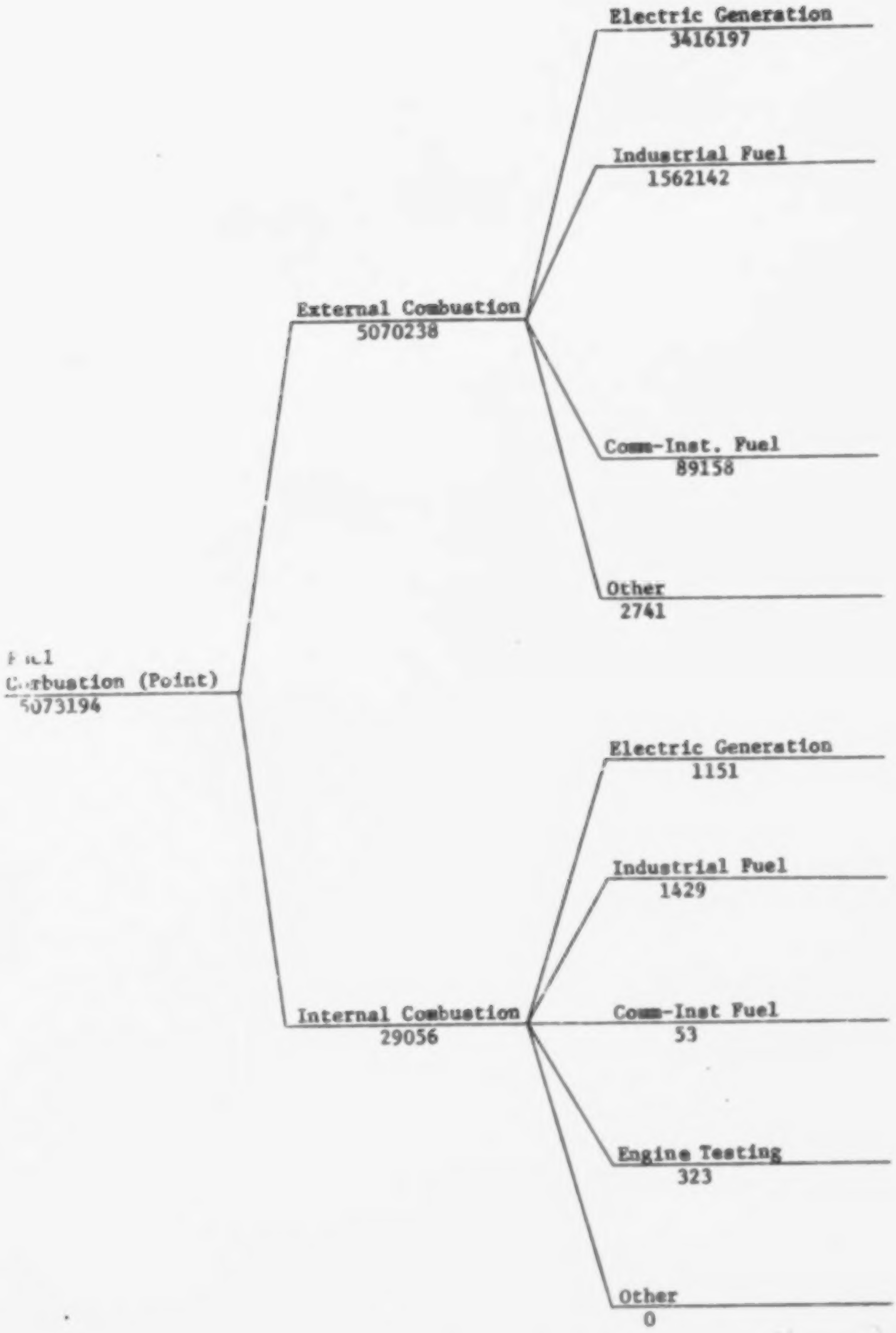
Electric Generation
3416197
Industrial Fuel
1562142
External Combustion
5070238
Comm-Inst. Fuel
89158
Other
2741
Fuel
Combustion (Point)
5073194
Electric Generation
1151
Industrial Fuel
1429
Internal Combustion
29056
Comm-Inst Fuel
53
Engine Testing
323
Other
0

Figure 2.3 (cont.)

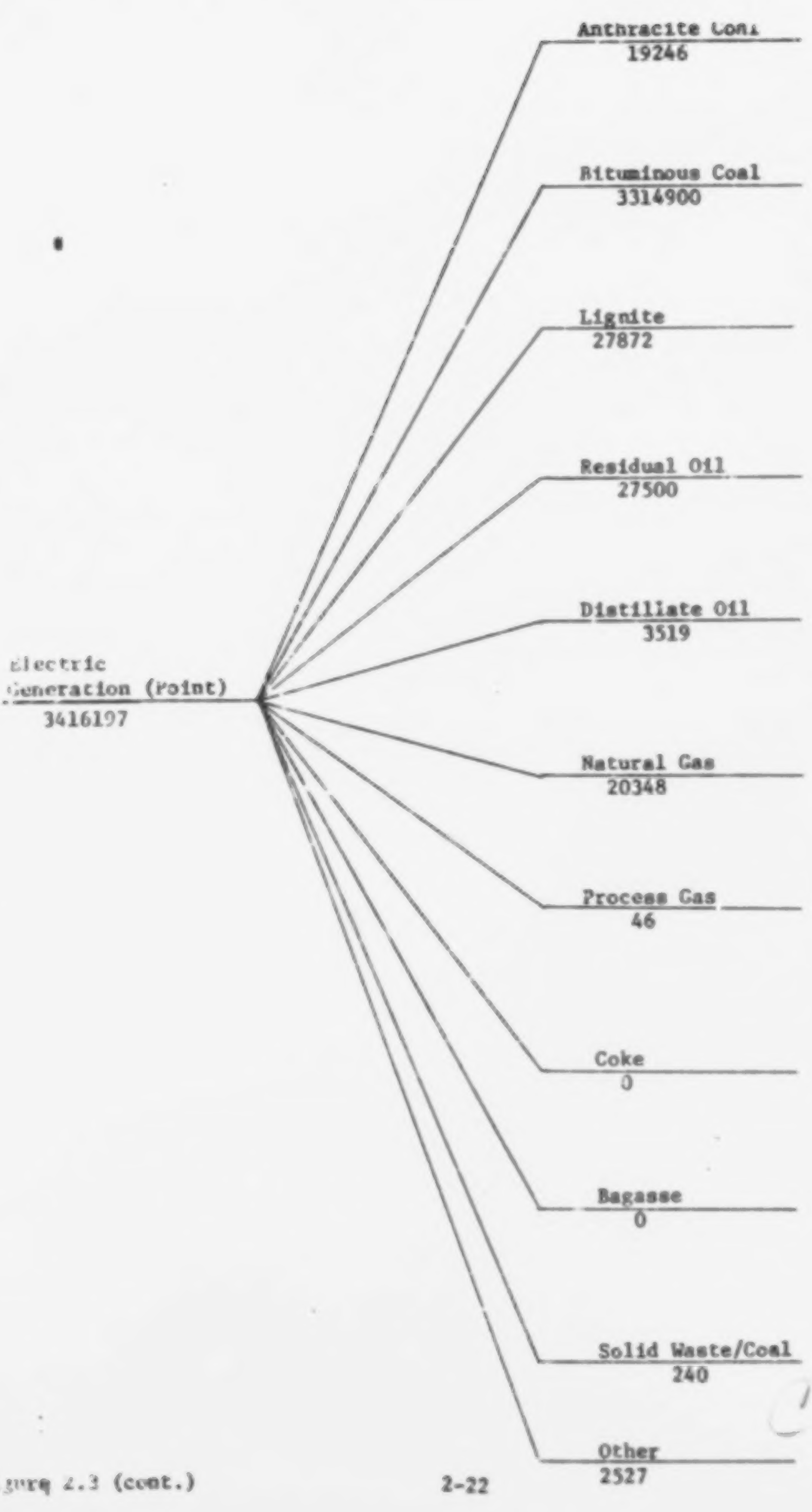
Electric
Generation (Point)
3416197
Anthracite Coal
19246
Bituminous Coal
3314900
Lignite
27872
Residual Oil
27500
Distillate Oil
3519
Natural Gas
20348
Process Gas
46
Coke
0
Bagasse
0
Solid Waste/Coal
240
Other
2527

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Figure 2.3 (cont.)

The basic theoretical development proceeds as follows. The linear model

$$Q^2 \Theta^2 = \sum_{K=1}^{N} Q_K^2 \sigma_K^2 \tag{1}$$

where

Q_K = air pollutant produced by source subclass K

100 σ_K = percentage error associated with Q_K

$Q = \sum_{K=1}^{N} Q_K$

100 Θ = percentage error associated with Q

N = number of subclasses in the source class

is postulated as an appropriate model to analyze propogation of error throughout the emissions inventory, for hte reasons stated above. For example, with reference to the external combustion node of Figure 2.3, we would have

Q_1 = 3415197 tons/yr.

Q_2 = 1562142 tons/yr.

Q_3 = 89158 tons/yr.

Q_4 = 2741 tons/yr.

$Q = \sum_{K=1}^{4} Q_K$ = 5070238 tons/yr.

Dividing both sides of equation (1) by $Q^2\Theta^2$

$$1 = \sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \tag{2}$$

The objective of this analysis is to obtain σ_K for each class k according to some value of Θ (error in total). As a first approximation we can assume that each term in Equation (2) contributes the same amount to the total.

$$\frac{1}{N} = \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \tag{3}$$

whence

$$\sigma_K = \frac{\Theta}{\sqrt{N}\,(Q_K/Q)}$$

where N is the number of source classes.

As a second approximation, the analysis can be modified to recognize the fact that each source class k contributes to the total error an amount proportional to its relative physical contribution to the total pollutant emission Q, as given by the ratio Q_K/Q. Analytically, it is only necessary to note that

$$\sum_{K=1}^{N} \frac{Q_K}{Q} = 1$$

Therefore, from equation (2):

$$\sum_{K=1}^{N} \frac{Q_K}{Q} = \sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \tag{5}$$

Equating both sides of ea. (5) term-by-term is equivalent to assuming that each term contributes to the total an amount proportional to Q_K/Q:

$$\frac{Q_K}{Q} = \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \tag{6}$$

whence

$$\sigma_K = \Theta \sqrt{\frac{Q}{Q_K}} \tag{7}$$

We can interpret Equation (7) as indicating the percent error allowable (σ_K) in forecasting emissions from source class K given the percent error desired (Θ) in forecasting total emissions. σ_K can be modified either by changing Θ or by regrouping the source classes, which changes Q/Q_K . The latter method is particularly useful in that it allows modification of σ_K without changing Θ . A useful policy for regrouping the source classes is to assemble the classes with the smallest emissions into one or more classes; however, this policy should be applied with some discretion in order to have groups or classes that can be successfully forecast.

In order to illustrate the application of the technique, let Θ = 5% for the external combustion node of Figure 2.3. The allowable errors for the component branches as computed from equation (7) are as follows:

$$\sigma_1 = 5\sqrt{\frac{5070238}{3416197}} = 6.09\%$$

$$\sigma_2 = 5\sqrt{\frac{5070238}{1562142}} = 9.01\%$$

$$\sigma_3 = 5\sqrt{\frac{5070238}{89158}} = 37.70\%$$

$$\sigma_4 = 5\sqrt{\frac{5070238}{2741}} = 215.04\%$$

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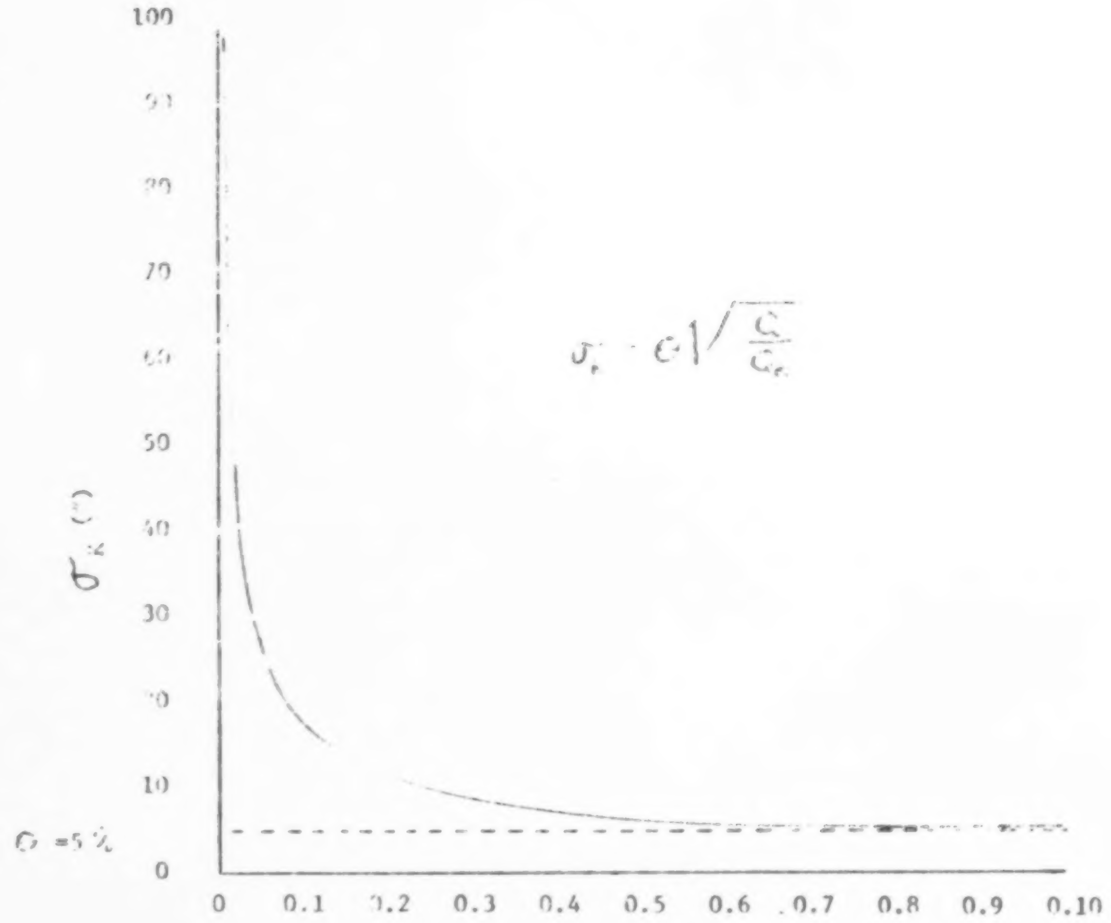

RELATIONSHIP BETWEEN σ_K AND Q_K/Q

Figure 2.4

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The allowable errors in physical units are:

$\sigma_1 Q_1 = \pm$ 208046.39 tons/year

$\sigma_2 Q_2 = \pm$ 140748.99 tons/year

$\sigma_3 Q_3 = \pm$ 33612.56 tons/year

$\sigma_4 Q_4 = \pm$ 5894.24 tons/year

The analysis demonstrates that, to obtain a known level of precision in the total emissions for a source class, not all source subclasses need to be measured with the same precision. Furthermore, the analysis shows that the probable error of the sum of emissions is less than the sum of the probable error of the component emissions. In fact, it is the square root of the weighted sum of the squared probable errors of the components, as can be readily observed by solving equation (1) for θ to obtain

$$\theta = \sqrt{\sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \sigma_K^2} \qquad (8)$$

Figure 2.4 displays the resulting relationship between σ_K and Q_K/Q in graphic form. When Q_K is a very small fraction of Q, the allowable value of σ_K is much larger than the allowable overall error θ, increasing exponentially as Q_K/Q approaches zero. On the other hand, σ_K approaches θ asymptotically as Q_K/Q approaches one. In general,

$\sigma_K \geq \Theta$, k = 1 .., N, with the equality sign holding only in the limiting case where there is only a single source subclass. Naturally, if there is a single source subclass, $Q_K = Q$ and σ_k must be equal to Θ if the latter is to be satisfied. Otherwise, the component emission errors σ_K will be allowed to have values greater than the overall emission error Θ. With respect to Figure 2.4, it is also interesting to note that the shape of the function is invariant to the value of Θ, i.e., perturbing the value of Θ would merely shift the horizontal asymptote of the curve. This conclusion has a significant practical implication, i.e., for any given value of Θ, the σ_k's can be allowed to have values greater than Θ. This conclusion has significant impact in determining the required accuracy of measurement of emission rates, and emission factors for individual source classes. In turn, these conclusions are useful in allocating resources to the determination or measurement of various emission parameters. Hierarchial application of the technique to the complete emissions data tree will result in σ_K's much greater than the grand total Θ as the computations proceed to successively lower levels of aggregation. Sample numerical analyses for complete emission inventories will be presented in the next section.

In the case where one or more of the σ_K's in a group are to be fixed by the analyst, it is shown in Appendix A that equation (7) changes to

$$\sigma_K = \Theta \sqrt{\frac{Q}{Q_K}\left(\frac{1 - D \cdot \tilde{Q}}{1 - \tilde{Q}}\right)} \tag{8}$$

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where

$$D = \sum_{K=m+1}^{N} \left[\left(\frac{Q_K \sigma_K}{Q \theta} \right)^2 - \frac{Q_K}{Q} \right] \tag{9}$$

and

$$\tilde{Q} = \sum_{K=m+1}^{N} \frac{Q_K}{Q} \tag{10}$$

in the general case where σ_K is unknown for k = 1, 2, ..., m and fixed for k = m + 1, ..., N. Even assuming $\sigma_k \doteq +0$ for k = 1, ..., m, there is, of course, a maximum value that σ_K can be fixed at for k = m + 1, ..., N and still satisfy a given overall error θ . This upper bound is also shown in Appendix A to be given by the formula

$$\sigma_K = \theta \sqrt{\frac{Q}{Q_K} \left(\frac{Q}{Q - \sum_{K=1}^{m} Q_K} \right)} \tag{11}$$

These extensions of the basic weighted sensitivity analysis will provide the analyst valuable guidance in performing the hierarchial error analysis of the emissions inventory so as to retain the integrity of the allowable error at the grand total level of emissions.

CONFIDENCE LEVEL FOR THE EMISSIONS INVENTORY

The weighted sensitivity analysis technique presented in the previous section serves to compute accuracy requirements for the component parts of an emissions inventory so as to insure that a given accuracy requirement for the overall inventory is not violated. By using Chebyshev's inequality it is possible to go one step further and establish in formal probabilistic terms the confidence level for the inventory, i.e., what is in fact the probability that the actual overall error in emissions will not exceed θ .

Chebyshev's theorem (Reference 3) states that if a probability distribution has mean $\bar{Q}$ and standard deviation θ , the probability of obtaining a value which deviates from the mean by more than λ standard deviations is less than λ^{-2}. Symbolically, in percentage error terms

$$P\left(\frac{|Q-\bar{Q}|}{Q} > \lambda\theta\right) < \frac{1}{\lambda^2} \qquad (12)$$

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where Q is the measured grand total emissions, as before. It is important to note that Chebyshev's result is distribution-free. In other words, inequality (12) applies regardless of what probability distribution is associated with the emissions data. This is critically important because the actual probability distributions of the various emissions are generally unknown.

Letting $\alpha = \lambda\theta$, inequality (12) becomes

$$P\left(\frac{|Q-\bar{Q}|}{Q} > \alpha\right) < \frac{\theta^2}{\alpha^2} \qquad (13)$$

and the fraction θ^2/α^2 gives a percentage confidence level for the inventory, i.e., the probability that the actual percentage error exceeds α is less than $\epsilon = \theta^2/\alpha^2$. As a numerical example, if it is desired to attain a 95% confidence level that the percentage emissions error will be within a 20% interval of the true value, then setting

$$\theta = \alpha\sqrt{\epsilon} = 0.20\sqrt{1-0.95} = 447\%$$

and applying the weighted sensitivity analysis technique to compute the σ_π's results in a set of precision requirements which, if satisfied, insure that the 95% confidence level for the emissions inventory has been attained. Using the same technique, Table 2-1 summarizes the required value

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Confidence Level

Acceptance Internal	α \ 1-C	90%	95%	99%
	5%	1.58%	1.12%	0.5%
	10%	3.16%	2.24%	1.0%
	20%	6.32%	4.47%	2.0%

Table 2.1 Values of Θ for selected pairs (α, 1-C)

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of for selected trade-offs between confidence level and accuracy of the for selected trade-offs between confidence level and accuracy of the emissions inventory. For example, σ must be set at 2.24% to attain 95% confidence level for the overall inventory error to be within 10%, 6.32% for 90% assurance of it being within 20%, etc.

In summary, the analysis of random error in emissions data should be undertaken as a two-step procedure: first, establish the desired value of the overall allowable error σ as a trade-off between confidence level and acceptable error interval, by means of Chebyshev's theorem; second, compute the required values for all component errors σ_k so as to preserve the integrity of σ, using the weighted sensitivity analysis technique.

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SOURCE INVENTORY AND
EMISSION FACTOR ANALYSIS

VOLUME [illegible]

PRELIMINARY
DRAFT

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Prepared for

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Research Triangle Park, North Carolina 27711

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PEDCO

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1.0 INTRODUCTION

Air pollutant emission inventories have been made for every major metropolitan region in the United States pursuant to submittal of State Implementation Plans under the Clean Air Act. Additional emission inventories are undertaken to implement the control efforts of various state, regional, and local agencies and to provide a base for research and development of air pollution control technology.

This report describes a Source Inventory and Emission Factor Analysis (SIEFA), a program designed to determine the precision of emission inventories. Through application of the SIEFA program, users of the data generated in an emission inventory will have at hand not only the values derived from emission calculations but a definition of their quality; that is, a statement of the statistical precision of each value and the precision of the overall emission inventory. Throughout this report these words have the following meaning:

Precision - A measure of variability, due to unknown factors which affect a measurement made on similar elements from a population. This variability is assumed to be random.

Accuracy - The degree to which data are biased.

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The precision values generated herein are not actually "true" precision, but rather the best estimate of precision that could be obtained.

The SIEFA program is based on and is compatible with the National Emissions Data System (NEDS) of the Environmental Protection Agency. As the national repository for air-pollution-related data, NEDS provides the format for virtually all substantive emissions inventories performed by agencies, groups, and individuals nationwide. NEDS computer programs and coding forms, together with the EPA "Compilation of Air Pollutant Emission Factors"(AP-42), are the basic tools of an emission inventory. SIEFA is able to accomodate changes to the program, such as a change in an emission factor or an additional SCC. For specific instructions regarding changes, refer to the SIEFA Users Manual, Volume III to this report.

In formulating the SIEFA program, PEDCo has calculated or estimated a precision value for each individual emission factor used in the NEDS. In this report we show how each precision value was derived and document the basis for each assumption or estimate involved. Where an emissions value is based on several parameters, such as control device efficiency, process thruput, or sulfur/ash content of fuels, a statistical or engineering analysis is applied to determine the precision of each parameter. By statistical scrutiny of each component of input, the SIEFA program thus indicates the level of confidence that can be assigned to an emission inventory. The output from SIEFA presents precision in terms of the standard deviation (S) of the estimated emissions. For computational purposes it is necessary to use the variance (i.e., Var (E) = S^2). The variance of an emission value is calculated by the equation:

$$\mathrm{Var}(E) = E^2 [P_1{}^2 + P_2{}^2 + \cdots + P_n{}^2]$$

where E = emissions in tons/yr.

P_1, P_2, etc. = Precision of the various factors used to calculate E.

Precision is defined as follows:

$$P_i = \frac{S_i}{\overline{X}_i}$$

where

S_i = standard deviation

$\overline{X}_i$ = arithmetic mean

The variance of the total emissions in any source category is the sum of the variances of the individual emissions. The measure of error or precision associated with an emission value is stated in terms of standard deviation. Standard deviation is the square root of variance. A flow chart outlining the basic steps followed by the SIEFA program in calculating the precision of an emission inventory is shown in Figure 1.1.

SIEFA provides an indication of both precision and accuracy of emission values, but in different ways. The output format gives precision values quantitatively, as standard deviations. Similar quantitative values for accuracy cannot be determined, however, since any known methods of finding a 'true' emissions value are

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Figure to be supplied.

Figure 1.1 Flow chart of the SIEFA program.

either impractical or are themselves subject to error, or both. Efforts in the direction of finding 'true' emissions values, such as auditing of company records or supervision of source testing, are beyond the scope of the SIEFA program.

With respect to the accuracy of emission factors, it is widely recognized that some are based on very meager data and in fact could not be representative of all sources in a category to which they are applied. In efforts to maintain the best possible array of working data, EPA updates the AP-42 emission factors whenever new information obtained in source testing or by some other reliable method provides a basis for revision. In addition, SIEFA increases the accuracy of emissions reporting by providing approximated values where elements of data are missing. Since the SIEFA output clearly shows how many values are thus approximated, it provides the user with an index to the relative accuracy of the values. Methods of determining and applying the approximated values are discussed in Section 4.

This report is presented in three major parts: Section 2 develops precision values for data on emissions from point sources; Section 3 deals with emissions from area sources; Section 4 presents a system for computerizing the quality analysis of emissions data.

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2.0 PRECISION OF POINT SOURCE EMISSIONS DATA

In the EPA procedure for preparing emissions inventories, emissions from point sources are calculated from data recorded on the NEDS point source coding form (Figure 2.1). Precision of the emission estimates is determined by the precision of these input data. For point sources the factors used to calculate emissions are the emission factor, control device efficiency, thruput, and sulfur or ash content of fuel. Code numbers that indicate the method used to estimate the emission factor are entered, by pollutant, on card 4, columns 66 through 70, of the point source form. Values for control efficiency are entered on card 3, columns 53 through 67; for thruput (annual operating rate), on card 6, columns 26 through 32; and for sulfur and ash content, on card 6, columns 40 through 45.

In the following sections we analyze the methods by which these values are derived and develop a precision value to characterize each entry. These precision values then are entered into the SIEFA program for use in evaluating the precision of source inventories and emission data to meet the needs of the requestor.

2.1 PRECISION OF EMISSION FACTORS

Card 4 of the NEDS point source form indicates the method used in estimating emission factors. Codes are provided for

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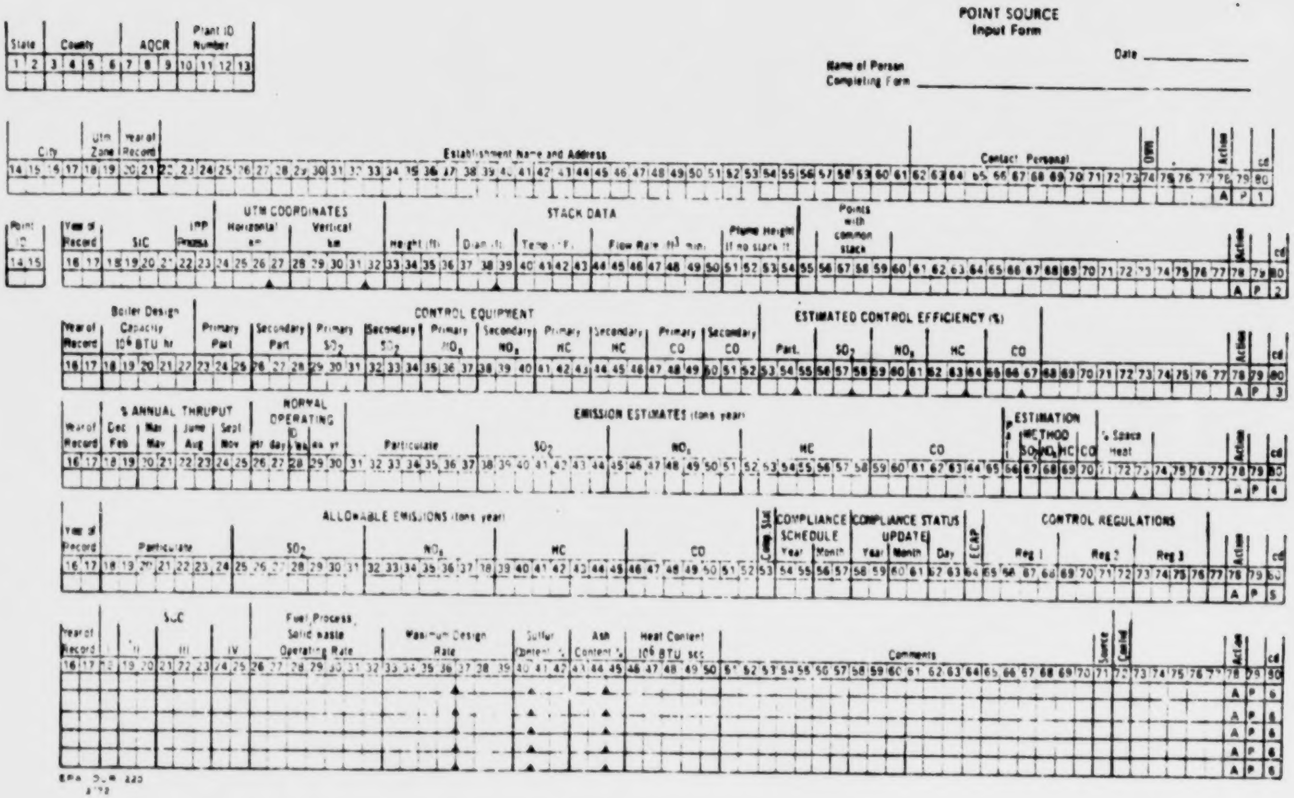

POINT SOURCE
Input Form

Name of Person Completing Form ____________________ Date __________

State	County	AQCR	Plant ID Number
1 2	3 4 5 6	7 8 9	10 11 12 13

City	Utm Zone	Year of Record	Establishment Name and Address	Contact Personal	OWN		Action		cd
14 15 16 17	18 19	20 21	22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	62 63 64 65 66 67 68 69 70 71 72 73	74	75 76 77	78	79	80
							A	P	1

Point ID	Year of Record	SIC	IPP Process	UTM COORDINATES Horizontal km	UTM COORDINATES Vertical km	STACK DATA Height (ft)	STACK DATA Diam (ft)	STACK DATA Temp (°F)	STACK DATA Flow Rate (ft³/min)	Plume Height if no stack (ft)		Points with common stack		Action		cd
14 15	16 17	18 19 20 21	22 23	24 25 26 27	28 29 30 31 32	33 34 35 36	37 38 39	40 41 42 43	44 45 46 47 48 49 50	51 52 53 54	55	56 57 58 59	60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77	78	79	80
														A	P	2

Year of Record	Boiler Design Capacity 10^6 BTU/hr	CONTROL EQUIPMENT Primary Part	Secondary Part	Primary SO_2	Secondary SO_2	Primary NO_x	Secondary NO_x	Primary HC	Secondary HC	Primary CO	Secondary CO	ESTIMATED CONTROL EFFICIENCY (%) Part.	SO_2	NO_x	HC	CO		Action		cd
16 17	18 19 20 21 22	23 24 25	26 27 28	29 30 31	32 33 34	35 36 37	38 39 40	41 42 43	44 45 46	47 48 49	50 51 52	53 54 55	56 57 58	59 60 61	62 63 64	65 66 67	68 69 70 71 72 73 74 75 76 77	78	79	80
																		A	P	3

Year of Record	% ANNUAL THRUPUT Dec Feb	Mar May	June Aug	Sept Nov	NORMAL OPERATING hr/day	days/wk	wk/yr	EMISSION ESTIMATES (tons/year) Particulate	SO_2	NO_x	HC	CO	ESTIMATION METHOD Part	SO_2	NO_x	HC	CO	% Space Heat		Action		cd
16 17	18 19	20 21	22 23	24 25	26 27	28	29 30	31 32 33 34 35 36 37	38 39 40 41 42 43 44	45 46 47 48 49 50 51	52 53 54 55 56 57 58	59 60 61 62 63 64 65	66	67	68	69	70	71 72 73	74 75 76 77	78	79	80
																				A	P	4

Year of Record	ALLOWABLE EMISSIONS (tons/year) Particulate	SO_2	NO_x	HC	CO	Comp Stat	COMPLIANCE SCHEDULE Year	Month	COMPLIANCE STATUS UPDATE Year	Month	Day	ECAP	CONTROL REGULATIONS Reg 1	Reg 2	Reg 3		Action		cd
16 17	18 19 20 21 22 23 24	25 26 27 28 29 30 31	32 33 34 35 36 37 38	39 40 41 42 43 44 45	46 47 48 49 50 51 52	53	54 55	56 57	58 59	60 61	62 63	64	65 66 67 68	69 70 71 72	73 74 75 76	77	78	79	80
																	A	P	5

Year of Record	SCC I	II	III	IV	Fuel, Process, Solid waste Operating Rate	Maximum Design Rate	Sulfur Content %	Ash Content %	Heat Content 10^6 BTU/scc	Comments	Source	Control		Action		cd
16 17	18	19 20	21 22 23	24 25	26 27 28 29 30 31 32	33 34 35 36 37 38 39	40 41 42	43 44 45	46 47 48 49 50	51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70	71	72	73 74 75 76 77	78	79	80
														A	P	6
														A	P	6
														A	P	6
														A	P	6
														A	P	6

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Figure 2.1. Point source coding form.

five methods of estimation:

Code	Method
1	Source-test data or other emission measurements.
2	Material balance based on engineering knowledge and expertise.
3	Emission factors from EPA's Compilation of Air Pollutant Emission Factors, AP-42.
4	Guess.
5	Special emission factor that differs from the official EPA factor.

All five estimation methods are considered as providing emission factors. Source test data and material balances are given in pounds per hour or pounds per ton; these rates are essentially emission factors. Methods 3 and 5 entail use of values that are emission factors by definition. Values determined by guess, Method 4, are often based on emission factors determined for similar processes.

Precision values for emission factors determined by each of these methods are calculated in the following sections. The results provide a precision value for each emission factor by Source Classification Code (SCC); values are given in Tables G-1 through G-5 of Appendix G.

2.1.1 Precision of Emission Factors Determined by Method 1

In effect, the number obtained in a source test is an emission factor for that specific source. PEDCo therefore studied the source test data on file with the EPA Emissions Measurements Branch to determine the precision of these data. This was done by calculating the standard deviation of each test series for various processes and pollutants. These calculations indicated that precision $\left(\frac{\sigma\bar{x}}{\bar{x}}\right)$ of the values obtained in source tests appears to depend on the pollutant.

We therefore selected at random 20 test series for each pollutant and calculated an average precision for each pollutant. Data obtained from the Emissions Measurements Branch were supplemented by test data from PEDCo files to complete a 20-test series for each pollutant. Results of the calculations are shown below.

Pollutant	Average Precision of Test Data
Particulate	0.196
SO_2	0.177
NO_x	0.134
HC	0.203
CO	0.321

These precision values were entered into the SIEFA program. Calculations of these values are shown in Appendix D.

2.1.2 Precision of Emission Factors Determined by Method 2

In Method 2 emissions are calculated by a material balance. A material balance can be made for some processes that emit particulate, SO_2, or HC. A material balance cannot be made for any process emitting NO_x or CO. Material balances were classified as involving either a chemical process (i.e. oxidation of sulfur contained in fuel) or a product loss (i.e. determined by amount of catalyst purchased for makeup for FCC units). The precision values assigned were based on the following criteria:

Basis of Material Balance	AP-42 E.F. Available	Basis of Precision Estimate
Chemical Process	Yes	Same as AP-42
Chemical Process	No	Engineering analysis
Product Loss	Yes	Size of total emission estimate
Product Loss	No	

2.1.2.1 Material Balance for SO_2 Emissions - The pollutant for which the majority of sources are amendable to material balance is SO_2. All of the SO_2 material balances are for oxidation of sulfur contained in fuel. For some sources an AP-42 emission factor was also available; in these cases the material balance was assigned the same precision value that is assigned to the emission factor, since the AP-42 emission factor incorporates the percent conversion from sulfur to SO_2. For the processes that are not assigned an AP-42 emission factor, an engineering analysis was performed to determine the precision of the material balances, as described in the following paragraphs.

Lignite boilers - Lignite contains sulfur in the form of pyrite and organic sulfur compounds, such as mercaptors. Pyrite sulfur content ranges from 30 to 80 percent. Organic sulfides are easily oxidized, whereas the pyrites are more difficult to oxidize. The high moisture content (30 to 60 percent) of some sulfur compounds also hinders oxidation. Some of the sulfur is converted to calcium sulfate, but most is oxidized to SO_2 or SO_3. Sodium oxide content of the lignite also has a profound effect on SO_x emissions. Low-sodium lignite emits almost all

(90 percent or greater) of the sulfur as SO_x, whereas high-sodium lignite emits only half the sulfur as SO_x. It is, therefore, very difficult to generalize a percentage conversion of sulfur in lignite to sulfur oxide. Under good combustion conditions (i.e. the lignite is pulverized), yields of 90 to 98 percent SO_x are expected; under poor conditions (the lignite is moist, has high sodium content, occurs in large lumps), the SO_x yields can be as low as 50 percent. Most lignite boilers incorporate a pulverization system and/or a moisture-reducing process. Conversion is estimated to be around 90 percent, with a possible range of 50 to 98 percent. Assuming at least five observations:

$$\sigma' = \frac{\max - \min}{d_2}$$

$$d_2 = 2.33$$

$$\sigma' = \frac{98 - 50}{2.33} = 20.6\%$$

$$\sigma_x = \frac{\sigma'}{\sqrt{n}} = \frac{20.6}{2.236} = 9.2\%$$

$$\text{Precision of conversion estimate} = \frac{\pm 9.2\%}{90\%} = \pm 0.102$$

The sulfur content of lignite may range between 0.3 and 2.3 percent by weight. ASTM Designation: D271-48[1] specifies the precision of determination of sulfur content to be within the following limits:

$\% \; S < 2.0$ error = 0.1

$\% \; S \geq 2.0$ error = 0.2

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Therefore the precisions are:

$$0 \leq \%\ S < 2.0 \qquad p = \frac{0.1}{\%\ S}$$

$$2.0 \leq \%\ S \qquad p = \frac{0.2}{\%\ S}$$

Process gas boilers - Several types of processes produce a gas with sufficient heating value to be utilized in a boiler. Process gases include refinery gas, coke oven gas, etc. Most of the sulfur in these gases appears as H_2S, with some thiols present also. The compounds oxidize readily and should show approximately 98 percent conversion to SO_x compounds. Assuming that the majority of process gas boilers operate under good combustion conditions, the standard error should be no more than ± 5 absolute percent. Thus, the precision of the conversion value will be 5/98 = ± 0.051.

The sulfur content of process gas may vary from 0 to 300 grains per 100 cubic feet. ASTM Designation: D1072-56 specifies an absolute precision of ± 0.1 grain per 100 cubic feet for determining the sulfur content of manufactured gases. Assuming an average molecular weight of the gas to be 30, an error of 0.1 grain per 100 cubic feet is equivalent to $\pm\ 1.7 \times 10^{-4}$ percent of sulfur by weight. Therefore, the precision of the sulfur content values equals $\pm \frac{1.7 \times 10^{-4}}{\%\ S}$.

Coke boilers - Little of the sulfur present in coking coals is removed through the coke oven gas. The remaining sulfur is usually of pyritic form and averages 1 percent by weight. In the combustion of coke, high temperatures are maintained and around 90 percent conversion of sulfur to SO_x compounds is expected. Based on six observations cited in Reference 3, a precision may be calculated.

$$\sigma' = \frac{R}{d^2}$$

$$R = \max - \min = 100 - 77$$

$$d_2 = 2.53$$

$$\sigma' = \pm 9.1$$

$$\sigma_x = \frac{\sigma'}{\sqrt{6}} = \frac{9.1}{2.449} = \pm 3.7$$

$$\text{Precision} = \frac{\pm 3.7}{90} = 0.041$$

ASTM Designation: D271-48[1] also specifies the precision of determination of the sulfur content of coke as ± 0.05 absolute percent. The precision is then $\pm \frac{0.05}{\% S}$.

Boilers fueled by solid waste and coal - Some boilers are fueled by refuse mixed with coal. The sulfur content of the coal is easily determined, but that of the refuse depends on the type of refuse burned. If the refuse is garbage, the sulfur content is negligible[4] and the sulfur content of the coal determines SO_x emissions. Assume that such is the case. For most types of coal boilers, the mean conversion is 95 percent. On the basis of data for boilers burning wet, pulverized fuel (from Reference 3) and the method used in calculations for coke boilers, the precision is ± 0.118.

ASTM Designation: D27148[1] specifies the following permissible errors:

Sulfur Content	Permissible Error
< 2.0 %	0.1 %
≥ 2.0 %	0.2%

Sulfur content of United States coal range from 0.5 percent to 4.9 percent. Since solid waste/coal boilers are usually employed in power plants that burn coals having relatively high sulfur content, the precision is:

$0 \leq \% S \leq 2.0$	$0.1/\% S$
$2.0 \leq \% S$	$0.2/\% S$

Open burning of jet fuel - Open burning is not as efficient as combustion in a jet engine. Expected conversion is less, probably in the range of 70 to 90 percent.

$$\sigma' = \frac{90-70}{1.13} = 17.6$$

$$\sigma_x = \frac{17.6}{\sqrt{2}} = 12.5$$

$$\text{Precision} = \frac{12.5}{80} = \pm 0.156$$

The sulfur content would be a precise for engine testing. The precision equals $\frac{0.03}{\% S}$ for $0 \leq \% S < 0.5$.

Flare stacks - Analysis of determinations by material balance of emissions from flares indicated a high conversion from sulfur to SO_2. The maximum percent sulfur content that can be entered on the NEDS point source form is 9.99 percent. The sulfur content of flow to many petroleum flares, however, is much higher than

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this value. Therefore, sulfur contents above 9.99 percent remain unreported on the NEDS forms (for purposes of computer calculations). The ASME Power Test Codes do not give a precision value for determination of sulfur in refinery gas. Since both the flow to the flare and the sulfur content vary greatly during the year, sulfur content of the flare gas as reported by the refinery is not regarded as very precise. Because a material balance cannot be calculated from data on the NEDS form, it is assumed that the precision of a material balance for SO_2 emissions from flares is equal to precision of the least precise emission factor in that category.

The precisions assigned to material balances for coal boilers that are not given an AP-42 emission factor are determined by Method 4 (guess), since the precision of a guess is equal to the precision of the least precise emission factor in a particular category. The precision assigned to material balances for processes designated by NEDS as "other/not classified" are also the precisions of a guess.

2.1.2.2 Material Balance for Particulate Emissions- Particulate emissions could be determined by material balance for three processes: sand handling operations in iron production, and FCC or TCC catalytic cracker operations.

The material balance for sand handling operations involves the amount of make-up sand purchased to replace sand lost to the atmosphere. The amount of make-up sand purchased, however, is not normally reported to a high degree of precision. Precisions would be in the range of 50 ± 10, 25 ± 5, or 10 ± 2, giving a precision value of ± 0.200.

Material balances for particulate emissions from the catalytic crackers were based on the amount of catalyst purchased to make up losses of catalyst to the atmosphere. Some of the TCC catalyst losses , however, are due to discarding pellets that have been broken up but were not expelled to the atmosphere. Further, the thruput value entered on the NEDS forms is in thousands of barrels of fresh feed through the crackers, a value not related to the amount of catalyst purchased or lost. Therefore, since the thruput data in the computer is not compatible with catalyst make-up, the precision assigned to the material balance method is the same as that assigned to the AP-42 emission factor.

2.1.2.3 Material Balance for HC Emissions - The processes for which HC emissions could be determined by material balance are drycleaning, degreasing, surface coating, and printing. These processes all involve product losses, and precision is related to the thruput.

HC emissions from drycleaning are considered equal to the amount of solvent purchased, since the solvent is reused, and all losses of solvent are considered due to evaporation. On the NEDS form, however, emissions from drycleaning are reported as tons of clothes cleaned; since these units do not reflect the amount of solvent purchased, the precision assigned to the material balance method is the same as the precision of the emision factor.

Degreasing emissions also equal the amount of solvent purchased, since the solvent is reused and the only losses are due to evaporation. The units on the NEDS form for degreasing are tons of solvent used, which can be interpreted as tons of solvent purchased each year. Since the amount purchased equals the evaporation losses, precision of the material balance is based entirely on thruput, for which precision values are calculated separately (Section 2.3). The precision of the material balance estimate for degreasing, therefore, is zero.

Material balance calculations of HC emissions from surface coating include the HC content of the coating material. The precisions of the AP-42 emission factors are essentially the precision of determining the solvent content of the coating materials. Therefore, the precision of material balance estimates for surface coating is equal to the precision of the AP-42 emission factor. Since AP-42 gives no emission factor for surface coating operations designated as "other/not classified", values for these operations are assigned the precision value of the least precise emission factor in the category.

Emissions from printing can be calculated by material balance because, as in degreasing, the solvent is recovered and reused and the amount of solvent purchased is used to make up the amount lost by evaporation. The NEDS units for printing emissions are tons of solvent so the amount of solvent purchased is entered on the form. The only imprecision is in the thruput, and the material balance method itself is considered precise. Therefore, the precision of the material balance estimate for printing

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operations is zero.

2.1.3 Precision of Emission Factors Determined by Method 3

Method 3 entails use of the emission factors given in EPA's "Compilation of Air Pollutant Emission Factors," Publication No. AP-42. (Research Triangle Park, N.C., 2nd Edition, April 1973). These emission factors are referred to as AP-42 factors.

Because of the large number of emission factors used in NEDS, priorities were assigned to those processes and pollutants that account for the major portion of total emissions. These priority groupings, developed by EPA, are shown in Table 2.1. Because it is not practical for the system to consider only priority process/pollutants in determining precision of an overall emission inventory, an average precision for AP-42 emission factors was calculated by standard statistical methods.

The statistical analyses were based on the AP-42 factors and the observed values, as reported in references given in AP-42, on which the factors are based. Analysis of the references showed that the observed values are not reported consistently. Three basic inconsistencies appear: (1) the observed value was a controlled emission, i.e., a value measured or estimated downstream from an air pollutant control device, (2) the observed value was reported as negligible, and (3) the observed value was reported as a range. To account for these inconsistencies, the following rules were developed:

- A value reported for a controlled emission is not used in the statistical analysis, since efficiency of the control device is unknown.

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Table 2.1 PRIORITY PROCESS-POLLUTANT EMISSIONS

SHOWN RELATIVE TO TOTAL EMISSIONS FOR A TYPICAL YEAR

1. Particulates - total 17,132,000 tons/year

Pulverized, dry bottom, boiler (bituminous coal)	3,130,000
Cement manufacturing (wet and dry)	2,000,000
Industrial bituminous coal combustion (area)	1,350,000
Stone quarrying	950,000
Petroleum industry - process heater	800,000
Pulverized, wet bottom, boiler (bituminous coal)	650,000
Petroleum industry - fluidized carckers	600,000
Spreader stokers (bituminous coal)	550,000
Lime manufacturing	500,000
Asphalt concrete	460,000
Brick manufacturing	350,000
Ferroalloy - 90% FESI	235,000
Iron production - sintering	225,000
Ceramic clay	133,000
Iron production - blast furnace - agglomerate charge	126,000
	12,000,000

2. SO_x - total 29,300,000 tons/year

Pulverized, dry bottom, boiler (bituminous coal)	11,000,000
Copper smelter	2,900,000
Pulverized, wet bottom, boiler (bituminous coal)	2,200,000
Cyclone boiler (bituminous coal)	2,100,000
Fluidized crackers	1,320,000
Industrial coal combustion - bituminous coal - area sources	900,000
Spreader stoker (bituminous coal)	900,000
Residual oil	760,000
	21,000,000

3. NO_x - total 21,300,000 tons/year

Light vehicles (gasoline)	4,940,000
Petroleum industry - process heater	2,800,000
Pulverized, dry bottom, boiler (bituminous coal)	2,300,000
Natural gas (point)	1,480,000
Heavy vehicles (diesel)	1,140,000
Cyclone boiler (bituminous coal)	900,000
Pulverized, dry bottom, boiler (bituminous coal)	760,000
Heavy vehicles (gasoline)	700,000
Pulverized, wet bottom, boiler (bituminous coal)	650,000
Residual oil	532,000
Industrial natural gas combustion - area sources	223,000
Industrial coal combustion (bituminous) - area sources	176,000
	16,500,000

Table 2.1 (Continued) PRIORITY PROCESS-POLLUTANT EMISSIONS SHOWN RELATIVE TO TOTAL EMISSIONS FOR A TYPICAL YEAR

4. HC - 23,1000,000 tons/year

Light vehicles (gasoline)	10,520,000
Carbon black (channel process)	1,480,000
Heavy vehicles (gasoline)	1,400,000
Solvent evaporation loss (miscellaneous)	1,380,000
Gas handling evaporation	914,000
Off-highway (gasoline)	823,000
Petroleum storage - floating roof	426,000
Surface coating - paint	420,000
	17,400,000

5. CO - 99,600,000 tons/year

Light vehicles (gasoline)	57,000,000
Heavy vehicles (gasoline)	5,750,000
Off-highway (gasoline)	4,510,000
Petroleum industry - fluid crackers	4,400,000
Carbon black - channel process	4,300,000
Mov. bed. cat. crackers	2,530,000
Iron production (blast furnace/sintering)	2,130,000
Gray iron cupola	1,300,000
Carbon black - furnace process oil	521,000
Carbon black - furnace with gas/oil	480,000
	83,000,000

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- A value reported as negligible is not used in the statistical analysis since it cannot be equated to a value of zero.
- A value reported as a range is considered as one observation whose value is the mean. If no other observations are reported in the references, the range is considered as two observations (maximum and minimum) in calculating a standard deviation (S) and coefficient of variation (C.V.).

In calculating the standard deviation of an emission factor, one must consider that the emission factor (EF) is not always the mean ($\bar{X}$) of the observed values. While we are not certain which data were used in developing an emission factor, it is a reasonable assumption that the coefficient of variation of the emission factor ($C.V._f$) is approximately equal to the coefficient of variation of the mean of the observations ($C.V._{\bar{X}}$). Thus:

$$C.V._{\bar{X}} = \frac{S_{\bar{X}}}{\bar{X}} = C.V._f = \frac{S_f}{EF} \qquad \text{(eq. 1)}$$

Upon calculating $S_{\bar{X}}$ then, S_f is found thus:

$$S_f = EF \times C.V._{\bar{X}} \qquad \text{(eq. 2)}$$

The precision of the emission factor depends not only on the standard deviation but also on the number of observations upon which the standard deviation is based. In other words, the confidence level for an emission factor derived from 15 observations is greater than that for a number derived from 2 observations. The statistical expression for the variability of the emission factor is $\frac{S}{\sqrt{n}}$, which is also known as the standard error of the mean, or the standard error of the emission factor (E). Since emission factors are expressed in various units, E must be converted to a dimensionless number. This number is known as the precision (P) where:

$$P = \frac{E}{EF} \qquad \text{(eq. 3)}$$

In some instances the Source Classification Code (SCC) used in the NEDS includes more than one emission point, and emission values are the summation of emissions calculated from more than one emission factor. The standard deviation of the combined emission factor (EF_{sum}) is expressed as follows:

$$S_{sum} = (S_1{}^2 + S_2{}^2)^{1/2} \qquad \text{(eq. 4)}$$

Where S_1 and S_2 are the standard deviations of each of the separate emission factors.

Likewise, where the emission factor is expressed as a range, an average standard deviation (S_{avg}) must be estimated thus:

$$S_{avg} = 1/2\ (S_1{}^2 + S_2{}^2)^{1/2} \qquad \text{(eq. 5)}$$

2.1.3.1 Standard Deviation of AP-42 Emission Factors Based on Two or More Observations - The methods used for calculating the standard deviation ($S_{\bar{X}}$) of the mean of emission factor observations is determined by the number of observations upon which the emission factor is based. For this purpose, the AP-42 factors are divided into two groups: those based on 2 to 12 observations and those based on more than 12 observations.

For 2 to 12 observations, the standard deviation is determined from the following equation:

$$S_{\bar{X}} = (x_{max} - x_{min})/d_2 \qquad \text{(eq. 6)}$$

where x_{max} is the highest observation

x_{min} is the lowest observation

d_2 is an adjustment factor used to estimate the standard deviation of a universe and is given for each corresponding n for n = 1 to n = 12.[5]

For more than 12 observations, a normal distribution equation is used:

$$S_{\bar{X}} = \sqrt{\frac{n\Sigma x^2 - (\Sigma x)^2}{n\ (n - 1)}} \qquad \text{(eq. 7)}$$

2.1.3.2 Standard Deviation of AP-42 Emission Factors Based on Less Than Two Observations - Some AP-42 factors are based on only one observation; for others, not even one observation could be found in the references. In these cases the standard deviation can best be estimated by assuming that C.V.'s for all AP-42 factors tend to average, and that the emission factor is the mean of any observations that could have been made. The standard deviation then may be expressed thus:

$$S_f = C.V._{avg} \times EF \qquad \text{(eq. 8)}$$

$C.V._{avg}$ is determined by taking the average C.V. of all AP-42 factors based on five or more observations. These values are shown in Tables 2.2 through 2.6. Before the C.V.'s were averaged, selected values were discarded as non-representative. For example, if the mean of the observations was outside the EF + 50% range, the resultant C.V. was not used. Also we rejected

Table 2.2 CALCULATION OF COEFFICIENT OF VARIATION FOR ALL PARTICULATE EMISSION FACTORS

BASED ON FIVE OR MORE OBSERVATIONS

Process	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., $s_{\bar{x}}$	Coeff. of variation, $C.V._{\bar{x}}$	Comments regarding rejected values
Brick-periodic coal kiln	1.6A	10	1.29A	2.31A	1.79	C.V. out-of-line with other C.V.'s
Cement kiln - dry	245	10	244	159	0.652	
Cement kiln - wet	228	13	223	164	0.735	
Textile glass furnace-regen.	16.4	5	17.2	7.63	0.444	
Textile glass furnace-recup.	27.8	13	37.3	6.38	0.171	
Textile curing ovens	1.2	21	4.75	12.6	2.65	$\bar{x}$ outside EF ± 50% - range
Wool glass furnace-recup.	28.3	8	30.5	19.6	0.643	
Wool curing oven	3.5	6	13.7	13.2	0.964	$\bar{x}$ outside EF ± 50% - range
Wool cooling	1.3	5	1.31	1.59	1.21	
Gray iron cupola	17	6	13.6	8.78	0.646	
Steel foundry electric arc	13	29	11.7	8.21	0.702	
H_2SO_4 mfg. recovered sulfur	0.35-0.8	7	0.700	0.463	0.661	
H_2SO_4 mfg. dark virgin sulfur	0.32-6.3	7	2.57	2.18	0.848	
Inciner. mun. multi chamber	30	178	23.7	13.3	0.561	
Inciner. mun. multi chamber w/settling chamber	14	9	3.99	3.81	0.955	$\bar{x}$ outside EF + 50% - range
Incineration ind. & comm. multi chamber	7	13	3.85	2.01	0.522	
Incin. flue fed single chamber	30	12	37.1	21.3	0.574	
Incin. flue fed modified	6	6	5.08	2.09	0.411	
Open burning municipal refuse	16	6	30.1	17.8	0.591	$\bar{x}$ outside EF ± 50% - range
Agriculture field burning	17	14	15.3	3.91	0.256	

Table 2.2 (CONT'd.) CALCULATION OF COEFFICIENT OF VARIATION FOR ALL PARTICULATE EMISSION FACTORS

BASED ON FIVE OR MORE OBSERVATIONS

Process	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., $s_{\bar{x}}$	Coeff. of variation, C.V.$_{\bar{x}}$	Comments regarding rejected values
Asphaltic concrete	45	5	38.8	10.7	0.276	
(Bit.) pulv. general boiler	16A	18	15.4A	5.03A	0.327	
(Bit.) pulv. wet boiler	13A	89	13.1A	3.61A	0.276	
(Bit.) pulv. dry boiler	17A	34	18.3A	5.23A	0.286	
(Bit.) pulv. cyclone boiler	2A	44	2.72A	1.20A	0.441	
Spreader stoker	13A	17	12.4A	6.77A	0.546	
Indus. & comm. distillate oil	15	74	14.5	9.73	0.671	
Nat. gas dom. & comm. heating	19	5	18.3	11.4	0.623	
LPG dom. & commercial butane	1.9	5	1.70	1.06	0.624	
LPG dom. & commercial propane	1.8		1.58	0.985	0.623	
				Avg.	= 0.549	

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Table 2.3 CALCULATION OF COEFFICIENT OF VARIATION FOR ALL SULFUR DIOXIDE EMISSION FACTORS BASED ON FIVE OR MORE OBSERVATIONS

Process	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., $s_{\bar{x}}$	Coeff. of variation, $C.V._{\bar{x}}$	Comments regarding rejected values
Brick-periodic coal kiln	12S	10	11.7S	3.41S	0.292	
Copper roasters	60	8	605	377	0.623	$\bar{x}$ outside EF + 50% - range
Copper smelters	320	16	249	209	0.839	C.V. out of line with other C.V.'s
Copper converters	870	16	688	237	0.344	
H_2SO_4 mfg. 96% conversion	55	8	68.1	10.1	0.148	
H_2SO_4 mfg. 97% conversion	40	5	43.1	10.8	0.251	
H_2SO_4 mfg. 98% conversion	27	8	31.1	4.65	0.150	
(Bit.) pulv. wet boiler	38S	7	38.3S	12.0S	0.313	
(Bit.) pulv. dry boiler	38S	8	38.3S	11.4S	0.298	
Power plant residual oil	157S	78	131S	31.1S	0.237	
				Avg.	= 0.254	

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Table 2.4 **CALCULATION OF COEFFICIENT OF VARIATION FOR ALL NITROGEN OXIDE EMISSION FACTORS BASED ON FIVE OR MORE OBSERVATIONS**

Process	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., $s_{\bar{x}}$	Coeff. of variation, C.V.$_{\bar{x}}$	Comments regarding rejected values
Brick-periodic oil kiln	1.7	5	5.88	4.72	0.804	$\bar{x}$ outside EF ± 50% - range
Brick-periodic coal kiln	1.4	11	4.23	1.99	0.471	$\bar{x}$ outside EF ± 50% - range
Textile glass furnace-regen.	9.2	5	9.48	7.04	0.743	
Textile glass furnace-recup.	29.2	13	59.6	46.6	0.782	$\bar{x}$ outside EF ± 50% - range
Textile curing oven	2.6	18	3.01	10.0	3.22	C.V. - out of line with other C.V.'s
Wool glass furnace-recup.	1.7	8	2.26	2.04	0.903	
Wool curing oven	1.1	6	0.975	1.40	1.44	
Uncontrolled weak HNO_3 prod.	50-55	13	52.5	29.2	0.556	
Controlled weak HNO_3 prod.	2-7	6	11.6	11.3	0.974	
Incin. municipal multi chamber	3	21	2.99	1.11	0.371	
Incin. ind. & comm. multi cmbr	3	6	2.20	0.909	0.450	
Open burning municipal refuse	6	6	10.5	9.88	0.941	
Landscape refuse	2	5	2.10	1.50	0.714	
(Bit.) pulv. general boiler	18	11	14.7	3.33	0.227	
(Bit.) pulv. dry boiler	18	12	16.4	3.25	0.198	
Ind. & comm. resid. oil	40-80	591	72.1	5.07	0.070	C.V. out of line with other C.V.'s
Domestic oil	12	589	71.8	8.96	0.125	$\bar{x}$ outside EF ± 50% - range
Power plant resid. oil	105	477	100	109	1.09	
Ind. & comm. distillate oil	40-80	591	67.6	183	0.027	C.V. out of line with other C.V.'s
Power plant natural gas	600	28	409	104	0.254	

Table 2.4(cont'd.) CALCULATION OF COEFFICIENT OF VARIATION FOR ALL NITROGEN OXIDE EMISSION FACTORS BASED ON FIVE OR MORE OBSERVATIONS

Process	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., $s_{\bar{x}}$	Coeff. of variation, C.V.$_{\bar{x}}$	Comments regarding rejected values
Dom. & commercial natural gas	80-120	15	102	74.1	0.726	
LPG dom. & commercial butane	8-12	5	14.6	11.7	0.801	
LPG dom. & commercial propane	7-11	5	13.5	10.9	0.807	
				Avg. =	0.700	

Table 2.5 CALCULATION OF COEFFICIENT OF VARIATION FOR ALL HYDROCARBON EMISSION FACTORS

BASED ON FIVE OR MORE OBSERVATIONS

Process	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., $s_{\bar{x}}$	Coeff. of variation, C.V.$_{\bar{x}}$	Comments regarding rejected values
Brick-periodic coal kiln	0.9	10	0.305	0.091	0.298	$\bar{x}$ outside EF ± 50% - range
Pet. storage floating roof	(140) 40-210	58	280	351	1.25	
Incineration industrial and commercial multi chamber	3	9	1.73	1.29	0.746	
Agriculture field burning	20	14	12.0	5.02	0.418	
(Bit.) pulv. general boiler	0.3	7	0.27	0.342	1.27	
Ind. & comm. residual oil	3	73	14.4	9.40	0.653	$\bar{x}$ outside EF ± 50% - range
Dom. & commercial natural gas	8	5	25.8	35.7	1.38	$\bar{x}$ outside EF ± 50% - range
				Avg.	= 0.921	

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Table 2.6 CALCULATION OF COEFFICIENT OF VARIATION FOR ALL CARBON MONOXIDE EMISSION FACTORS BASED ON FIVE OR MORE OBSERVATIONS

Process	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., $s_{\bar{x}}$	Coeff. of variation, C.V.$_{\bar{x}}$	Comments regarding rejected values
Brick-periodic coal kiln	3.2	10	0.604	0.180	0.298	$\bar{x}$ outside EF $\pm$ 50% - range
Textile glass furnace-recup.	0.9	13	2.04	1.46	0.716	$\bar{x}$ outside EF + 50% - range
Textile curing oven	1.5	20	2.51	3.72	1.48	
Wool glass furnace-recup.	0.25	6	0.273	0.159	0.582	
Wool curing oven	1.7	5	1.74	0.984	0.566	
Steel production B.O.F.	139	8	163	48.4	0.297	
Agriculture field burning	100	14	98.2	25.0	0.255	
(Bit.) pulv. wet boiler	1	7	0.700	1.00	1.43	
Indus. & commercial resid. oil	4	22	3.93	1.20	0.305	
Power plant oil	3	9	2.46	2.78	1.07	
Indus. & commercial dist. oil	4	22	3.58	1.41	0.394	
Power plant natural gas	17	5	54.4	60.1	1.10	$\bar{x}$ outside EF $\pm$ 50% - range
				Avg.	= 0.709	

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those C.V.'s that were completely out of line with other C.V.'s for the same pollutant. Average C.V.'s by pollutant are as follows:

Pollutant	C.V.$_{avg}$
Particulate	0.549
SO_x	0.254
NO_x	0.700
HC	0.921
CO	0.709

2.1.3.3 Calculation of Precision of Each AP-42 Emission Factor - Having determined the standard deviation, and knowing the number of observations upon which the AP-42 factor is based, we calculated a precision value for each priority emission factor by use of eq. 3. These precision values are shown in Tables 2.7 through 2.11.

Precision values for non-priority emission factors were not calculated as a part of this study. In order to estimate precision of an overall emission inventory, then, we calculated and applied the average precision of all priority emission factors. These calculations are shown in Table 2.12 through 2.16. The average precisions of AP-42 emission factors as shown below by pollutant:

Pollutant	Average Precision
Particulate	0.211
SO_x	0.146
NO_x	0.172
HC	0.237
CO	0.357

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Table 2.7 PRECISION OF PARTICULATE EMISSION FACTORS FOR PRIORITY PROCESSES

SCC				Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	Std. dev. of obs., s_m	Coeff. of variation, C.V.	Std. dev. of emission factor, S_f EF x C.V.	Std. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
1	01	002	01	13A	89	13.1A	3.61A	0.276	3.59A	0.381A	0.029
1	01	002	02	17A	34	18.3A	5.23A	0.286	4.86A	0.833A	0.049
1	01	002	04	13A	17	12.4A	6.77A	0.546	7.10A	1.72 A	0.132
1	01	002	06	13A	89	13.1A	3.61A	0.276	3.59A	0.381A	0.029
1	01	002	07	17A	34	18.3A	5.23A	0.286	4.86A	0.833A	0.049
1	01	002	08	13A	17	12.4A	6.77A	0.546	7.10A	1.72 A	0.132
1	01	002	10	2A	1	a		0.549	1.10A	1.10 A	0.549
1	01	002	12	17A	34	18.3A	5.23A	0.286	4.86A	0.833A	0.049
1	02	002	01	13A	89	13.1A	3.61A	0.276	3.59A	0.381A	0.029
1	02	002	02	17A	34	18.3A	5.23A	0.286	4.86A	0.833A	0.049
1	02	002	04	13A	17	12.4A	6.77A	0.546	7.10A	1.72 A	0.132
1	02	002	07	13A	89	13.1A	3.61A	0.276	3.59A	0.381A	0.029
1	02	002	08	17A	34	18.3A	5.23A	0.286	4.86A	0.833A	0.049
1	02	002	09	13A	17	12.4A	6.77A	0.546	7.10A	1.72 A	0.132
1	02	002	12	17A	34	18.3A	5.23A	0.286	4.86A	0.833A	0.049
1	02	002	13	13A	17	12.4A	6.77A	0.546	7.10A	1.72 A	0.132
1	03	002	05	13A	89	13.1A	3.61A	0.276	3.59A	0.381A	0.029
1	03	002	06	17A	34	18.3A	5.23A	0.286	4.86A	0.833A	0.049
1	03	002	09	13A	17	12.4A	6.77A	0.546	7.10A	1.72 A	0.132
1	03	002	13	2A	1	a		0.549	1.10A	1.10 A	0.549
3	03	006	03	565	0	b		0.549	310	310	0.549
3	03	008	02	40	1	a		0.549	22.0	22.0	0.549
3	03	008	03	42	1	a		0.549	23.1	23.1	0.549
3	05	002	01	45	5	38.8	10.7	0.276	12.4	5.55	0.123
3	05	002	02	45	5	38.8	10.7	0.276	12.4	5.55	0.123

a) Where n is 1 or 0, average C.V., is used.
b) No reference available, emission factor is treated as one observation.
c) No observation found in references, emission factor is treated as one observation.

Table 2.7(Continued) PRECISION OF PARTICULATE EMISSION FACTORS FOR PRIORITY PROCESSES

SCC				Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	Std. dev. of obs., s_m	Coeff. of variation, C. V.	Std. dev. of emission factor, S_f EF x C.V.	Std. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
3	05	003	01	96	0	c		0.549	52.7	52.7	0.549
3	05	003	02	96	0	c		0.549	52.7	52.7	0.549
3	05	003	03	34	0	c		0.549	18.7	18.7	0.549
3	05	003	04	0.07	3	0.07	0.0278	0.397	0.0278	0.0161	0.230
3	05	003	05	0.07	6	0.89	0.447	0.502	0.0351	0.0143	0.204
3	05	003	06	1.30	14	1.70	2.11	1.24	1.61	0.331	0.255
3	05	006	01	46	10	45.8	29.8	0.651	29.9	9.46	0.206
3	05	006	02	18	1	a		0.549	9.88	9.88	0.549
3	05	006	03	245	10	244	159	0.652	160	50.6	0.207
3	05	006	04	245	10	244	159	0.652	160	50.6	0.207
3	05	006	05	245	10	244	159	0.651	160	50.6	0.207
3	05	007	01	42.8	12	41.8	34.1	0.816	34.9	10.1	0.236
3	05	007	02	6	0	c		0.549	3.29	3.29	0.549
3	05	007	03	228	12	223	182	0.816	186	53.7	0.236
3	05	007	04	228	12	223	182	0.816	186	53.7	0.236
3	05	007	05	228	12	223	182	0.816	186	53.7	0.236
3	05	008	01	70	2	17.1	0.442	0.0258	1.81	1.28	0.018
3	05	008	02	76	0	c		0.549	41.7	41.7	0.549
3	05	008	03	34	0	c		0.549	18.7	18.7	0.549
3	05	016	01	31	0	c		0.549	17.0	17.0	0.549
3	05	016	02	2	0	c		0.549	1.10	1.10	0.549
3	05	016	03	8	1	a		0.549	4.39	4.39	0.549
3	05	016	04	200	4	134	70.1	0.523	105	52.5	0.263
3	05	020	01	0.5	1	a		0.549	0.275	0.275	0.549
3	05	020	02	1.5	1	a		0.549	0.824	0.824	0.549

a) Where n is 1 or 0, average C.V., is used.
b) No reference available, emission factor is treated as one observation.
c) No observation found in references, emission factor is treated as one observation.

Table 2.7(Continued) PRECISION OF PARTICULATE EMISSION FACTORS FOR PRIORITY PROCESSES

SCC				Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	Std. dev. of obs., s_m	Coeff. of variation, C. V.	Std. dev. of emission factor, S_f EF x C.V.	Std. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
3	05	020	03	6	1	a		0.549	3.29	3.29	0.549
3	05	020	04	5	1	a		0.549	2.75	2.75	0.549
3	05	020	05	6	1	a		0.549	3.29	3.29	0.549
3	05	020	06	2	0	c		0.549	1.10	1.10	0.549
3	05	020	07	10	0	c		0.549	5.49	5.49	0.549
3	06	001	01	840	1	a		0.549	461	461	0.549
3	06	001	02	0.2	1	a		0.549	0.110	0.110	0.549
3	06	001	03	20	1	a		0.549	11.0	11.0	0.549
3	06	001	04	200	1	a		0.549	110	110	0.549
3	06	002	01	242	2	166	185	1.11	269	190	0.785

a) Where n is 1 or 0, average C.V., is used.
b) No reference available, emission factor is treated as one observation.
c) No observation found in references, emission factor is treated as one observation.

Table 2.8 PRECISION OF SULFUR DIOXIDE EMISSION FACTORS FOR PRIORITY PROCESSES

SCC				Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	Std. dev. of obs., s_m	Coeff. of variation, C. V.	Std. dev. of emission factor, S_f EF x C.V.	Std. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
1	01	002	01	38S	7	38.3S	12.0 S	0.313	11.9 S	4.50S	0.118
			02	38S	8	38.3S	11.4 S	0.298	11.3 S	4.00S	0.105
			03	38S	4	36.9S	3.30S	0.0894	3.40S	1.70S	0.045
			04	38S	1	a		0.254	9.65S	9.65S	0.254
			06	38S	7	38.3S	12.0 S	0.313	11.9 S	4.50S	0.118
			07	38S	8	38.3S	11.4 S	0.298	11.3 S	4.00S	0.105
			08	38S	1	a		0.254	9.65S	9.65S	0.254
			10	38S	1	a		0.254	9.65S	9.65S	0.254
			12	38S	8	38.3S	11.4 S	0.298	11.3 S	4.00S	0.105
1	01	004	01	157S	78	131 S	31.1 S	0.237	37.2 S	4.21S	0.027
			02	157S	78	131 S	31.1 S	0.237	37.2 S	4.21S	0.027
			03	157S	78	131 S	31.1 S	0.237	37.2 S	4.21S	0.027
1	02	002	01	38S	7	38.3S	12.0 S	0.313	11.9 S	4.50S	0.188
			02	38S	8	38.3S	11.4 S	0.298	11.3 S	4.00S	0.105
			03	38S	4	36.9S	3.30S	0.0894	3.40S	1.70S	0.045
			04	38S	1	a		0.254	9.65S	9.65S	0.254
			07	38S	7	38.3S	12.0 S	0.313	11.9 S	4.50S	0.188
			08	38S	8	38.3S	11.4 S	0.298	11.3 S	4.00S	0.105
			09	38S	1	a		0.254	9.65S	9.65S	0.254
			12	38S	8	38.3S	11.4S	0.298	11.3 S	4.00S	0.105
			13	38S	1	a		0.254	9.65S	9.65S	0.254
1	02	004	01	157S	78	131 S	31.1S	0.237	37.2 S	4.21S	0.0268
1	02	004	02	157S	78	131 S	31.1S	0.237	37.2 S	4.21S	0.027
			03	157S	78	131 S	31.1S	0.237	37.2 S	4.21S	0.027
1	03	002	05	38S	7	38.3S	12.0S	0.313	11.9 S	4.50S	0.188

a) Where n is 1 or 0, average C.V., is used.

b) No reference available, emission factor is treated as one observation.

c) No observation found in references, emission factor is treated as one observation.

Table 2.8(Continued) PRECISION OF SULFUR DIOXIDE EMISSION FACTORS FOR PRIORITY PROCESSES

SCC				Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St d. dev. of obs., s_m	Coeff. of variation, C. V.	St d. dev. of emission factor, S_f EF x CV.	St d. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
			06	38S	8	38.3S	11.4 S	0.298	11.3 S	4.00S	0.105
			09	38S	1	a		0.254	9.65S	9.65S	0.254
			13	38S	1	a		0.254	9.65S	9.65S	0.254
1	03	004	01	157S	78	131 S	31.1 S	0.237	37.2 S	4.21S	0.027
			02	157S	78	131 S	31.1 S	0.237	37.2 S	4.21S	0.027
			03	157S	78	131 S	31.1 S	0.237	37.2 S	4.21S	0.027
3	03	005	02	60	8	605	377	0.623	37.4	13.2	0.220
3	03	005	03	320	16	249	209	0.839	268	67.0	0.209
3	03	005	04	870	16	688	237	0.344	299	74.8	0.086
3	06	002	01	493	3	669	419	0.626	309	178	0.361

a) Where n is 1 or 0, average C.V., is used.
b) No reference available, emission factor is treated as one observation.
c) No observation found in references, emission factor is treated as one observation.

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Table 2.9 PRECISION OF NITROGEN OXIDE EMISSION FACTORS FOR PRIORITY PROCESSES

SCC				Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	Std. dev. of obs., s_m	Coeff. of variation, C.V.	Std. dev. of emission factor, S_f EF x C.V.	Std. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
1	01	002	01	30	12	16.4	3.25	0.198	5.94	1.71	0.057
			02	30	12	16.4	3.25	0.198	5.94	1.71	0.057
			03	55	3	36.3	29.4	0.810	44.6	25.7	0.467
			04	15	0	c		0.700	10.5	10.5	0.700
			06	30	12	16.4	3.25	0.198	5.94	1.71	0.057
			07	30	12	16.4	3.25	0.198	5.94	1.71	0.057
			08	15	0	c		0.700	10.5	10.5	0.700
			10	6	1	a		0.700	4.20	4.20	0.700
			12	30	12	16.4	3.25	0.198	5.94	1.71	0.057
1	01	004	01	105	477	100	109	1.09	114	5.22	0.050
			02	105	477	100	109	1.09	114	5.22	0.050
			03	105	477	100	109	1.09	114	5.22	0.050
1	01	006	01	600	28	409	104	0.254	152	28.7	0.048
			02	600	28	409	104	0.254	152	28.7	0.048
			03	600	28	409	104	0.254	152	28.7	0.048
1	02	002	01	30	12	16.4	3.25	0.198	5.94	1.71	0.057
			02	30	12	16.4	3.25	0.198	5.94	1.71	0.057
			03	55	3	36.3	29.4	0.810	44.6	25.7	0.467
			04	15	0	c		0.700	10.5	10.5	0.700
			07	30	12	16.4	3.25	0.198	5.94	1.71	0.057
			08	30	12	16.4	3.25	0.198	5.94	1.71	0.057
			09	15	0	c		0.700	10.5	10.5	0.700
1	02	002	12	30	12	16.4	3.25	0.198	5.94	1.71	0.057
			13	6	1	a		0.700	4.20	4.20	0.700
1	02	004	01	60	591	72.1	5.07	0.0703	4.22	0.174	0.003

a) Where n is 1 or 0, average C.V., is used.
b) No reference available, emission factor is treated as one observation.
c) No observation found in references, emission factor is treated as one observation.

Table 2.9 (Continued) PRECISION OF NITROGEN OXIDE EMISSION FACTORS FOR PRIORITY PROCESSES

SCC				Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	Std. dev. of obs., s_m	Coeff. of variation, C.V.	Std. dev. of emission factor, S_f EF x C.V.	Std. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
			02	60	591	72.1	5.07	0.0703	4.22	0.174	0.003
			03	60	591	72.1	5.07	0.0703	4.22	0.174	0.003
1	02	006	01	175	4	296	232	0.784	137	68.5	0.391
			02	175	4	296	232	0.784	137	68.5	0.391
			03	175	4	296	232	0.784	137	68.5	0.391
1	03	002	05	30	12	16.4	3.25	0.198	5.94	1.71	0.057
			06	30	12	16.4	3.25	0.198	5.94	1.71	0.057
			09	15	0	c		0.700	10.5	10.5	0.700
			13	6	1	a		0.700	4.20	4.20	0.700
1	03	004	01	60	591	72.1	5.07	0.0703	4.22	0.174	0.003
			02	60	591	72.1	5.07	0.0703	4.22	0.174	0.003
			03	60	591	72.1	5.07	0.0703	4.22	0.174	0.003
1	03	006	01	100	15	102	74.1	0.726	72.6	18.7	0.187
			02	100	15	102	74.1	0.726	72.6	18.7	0.187
			03	100	15	102	74.1	0.726	72.6	18.7	0.187
3	06	001	01	2900	1	a		0.700	2030	2030	0.700
			02	0.23	1	a		0.700	0.161	0.161	0.700
			03	69	1	a		0.700	48.3	48.3	0.700
			04	230	1	a		0.700	161	161	0.700

a) Where n is 1 or 0, average C.V., is used.
b) No reference available, emission factor is treated as one observation.
c) No observation found in references, emission factor is treated as one observation.

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Table 2.10 PRECISION OF HYDROCARBON EMISSION FACTORS FOR PRIORITY PROCESSES

SCC				Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	Std. dev. of obs., s_m	Coeff. of variation, C. V.	Std. dev. of emission factor, S_f EF x C.V.	Std. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
3	01	005	01	11500	0	c		0.921	10600	10600	0.921
4	02	001	01	1120	1	a		0.921	1030	1030	0.921
4	03	002	01	140	58	280	351	1.25	175	23.0	0.164
4	03	002	03	100	2	107	47.0	0.439	43.9	31.0	0.310

a) Where n is 1 or 0, average C.V., is used.
b) No reference available, emission factor is treated as one observation.
c) No observation found in references, emission factor is treated as one observation.

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Table 2.11 PRECISION OF CARBON MONOXIDE EMISSION FACTORS FOR PRIORITY PROCESSES

SCC				Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St d. dev. of obs., s_m	Coeff. of variation, C. V.	St d. dev. of emission factor, S_f EF x C.V.	St d. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
3	01	005	01	33500	0	c		0.709	23800	23800	0.709
3	01	005	03	5300	2	8640	6900	0.799	4230	2990	0.564
3	0.	005	04	4500	4	31900	16400	0.514	2310	1155	0.257
3	03	008	01	1750	2	1750	619	0.354	620	438	0.250
3	03	008	03	44	1	a		0.709	31.2	31.2	0.709
3	04	003	01	145	0	b		0.709	103	103	0.709
3	06	002	01	13700	1	a		0.709	9710	9710	0.709
3	06	003	01	3800	1	a		0.709	2690	2690	0.709

a) Where n is 1 or 0, average C.V., is used.
b) No reference available, emission factor is treated as one observation.
c) No observation found in references, emission factor is treated as one observation.

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Table 2.12 AVERAGE PRECISION OF PARTICULATE EMISSION FACTORS

SCC	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., s_m	Coeff. of variation, C. V.	St'd. dev. of emission factor, S_f EF x C.V.	St'd. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
1 01 002 01	13A	89	13.1A	3.61A	0.276	3.59A	0.381A	0.029
1 01 002 02	17A	34	18.3A	5.23A	0.286	4.86A	0.833A	0.049
1 01 002 04	13A	17	12.4A	6.77A	0.546	7.10A	1.72 A	0.132
3 05 002 01	45	5	38.8	10.7	0.276	12.4	5.55	0.123
3 05 003 04	0.07	3	0.07	0.0278	0.397	0.0278	0.0161	0.230
3 05 003 05	0.07	6	0.89	0.447	0.502	0.0351	0.0143	0.204
3 05 003 06	1.30	14	1.70	2.11	1.24	1.61	0.331	0.255
3 05 006 01	46	10	45.8	29.8	0.651	29.9	9.46	0.206
3 05 007 01	42.8	12	41.8	34.1	0.816	34.9	10.1	0.236
3 05 008 01	70	2	17.1	0.442	0.0258	1.81	1.28	0.018
3 05 016 04	200	4	134	70.1	0.523	105	52.5	0.263
3 06 002 01	242	2	166	185	1.11	269	190	0.785
							Avg.	= 0.211

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Table 2.13 AVERAGE PRECISION OF SULFUR DIOXIDE EMISSION FACTORS

SCC	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., s_m	Coeff. of variation, C. V.	St'd. dev. of emission factor, S_f EF x C.V.	St'd. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
1 01 002 01	38S	7	38.3S	12.0 S	0.313	11.9 S	4.50S	0.118
1 01 002 02	38S	8	38.3S	11.4 S	0.298	11.3 S	4.00S	0.105
1 01 002 03	38S	4	36.9S	3.30S	0.0894	3.40S	1.70S	0.0448
1 01 004 01	157S	78	131 S	31.1 S	0.237	37.2 S	4.21S	0.0268
3 03 005 02	60	8	605	377	0.623	37.4	13.2	0.220
3 03 005 03	320	16	249	209	0.839	268	67.0	0.209
3 03 005 04	870	16	688	237	0.344	299	74.8	0.0860
3 06 002 01	493	3	669	419	0.626	309	178	0.361
							Avg.	= 0.146

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Table 2.14 AVERAGE PRECISION OF NITROGEN OXIDE EMISSION FACTORS

SCC	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., s_m	Coeff. of variation, C. V.	St'd. dev. of emission factor, S_f EF x C.V.	St'd. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
1 01 002 01	30	12	16.4	3.25	0.198	5.94	1.71	0.0570
1 01 002 03	55	3	36.3	29.4	0.810	44.6	25.7	0.467
1 01 004 01	105	477	100	109	1.09	114	5.22	0.0497
1 01 006 01	600	28	409	104	0.254	152	28.7	0.0478
1 02 004 01	60	591	72.1	5.07	0.0703	4.22	0.174	0.00290
1 02 006 01	175	4	296	232	0.784	137	68.5	0.391
1 03 006 01	100	15	102	74.1	0.726	72.6	18.7	0.187
							Avg.	= 0.172

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Table 2.15 AVERAGE PRECISION OF HYDROCARBON EMISSION FACTORS

SCC	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., s_m	Coeff. of variation, C. V.	St'd. dev. of emission factor, S_f EF x C.V.	St'd. dev. of emission factor, E $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{E}{EF}$
4 03 002 01	140	58	280	351	1.25	175	23.0	0.164
4 03 002 03	100	2	107	47.0	0.439	43.9	31.0	0.310
							Avg.	= 0.237

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Table 2.16 AVERAGE PRECISION OF CARBON MONOXIDE EMISSION FACTORS

SCC	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., s_m	Coeff. of variation, C. V.	St'd. dev. of emission factor, S_f EF x C.V.	St'd. dev. of emission factor, ε $\frac{S_f}{\sqrt{n}}$	Precision, P $\frac{\varepsilon}{EF}$
3 01 005 03	5300	2	8640	6900	0.799	4230	2990	0.564
3 01 005 04	4500	4	31900	16400	0.514	2310	1155	0.257
3 01 008 01	1750	2	1750	619	0.354	620	438	0.250
							Avg.	= 0.357

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2.1.4 Precision of Emission Factors Determined by Method 4

Although it is not possible to calculate the precision of a guess, it is reasonable to estimate such precision. For example, given a specific process category, a guess cannot be any more precise than the most precise AP-42 factor within that category. As a practical matter, one cannot assume that a guess will be more precise than the least precise emission factor for the given category -- it may even be less precise. Since the exact precision cannot be determined, the unit emission factors used in calculating emissions by Method 4 were estimated to be as precise as the least precise AP-42 factor within that category.

2.1.5 Precision of Emission Factors Determined by Method 5

There is no basis for stating that an emission factor developed by, for example, a state air pollution control agency is any more precise than the corresponding AP-42 factor. Therefore an emission factor developed by a state or other agency is estimated to be as precise as the corresponding AP-42 factor. Where no AP-42 factor is given, but the process emits the pollutant in question, precision of the emission factor is estimated to be the same as that of a factor determined by guess (Method 4).

2.2 PRECISION OF CONTROL DEVICE EFFICIENCY VALUES

The precision of any value given for control device efficiency depends on how the number was derived by personnel completing the NEDS form. Methods for determining this three-digit number include the following:

a) Stack measurements before and after a control device.

b) Use of manufacturer's data.

c) Use of graphs for specific control devices relating efficiency to unit size, pressure drop, power requirements, and other parameters.

d) Estimation or guess.

Since there is no way of telling which of these methods led to the value entered on the neds data sheet, one must take a conservative apprcach in determining precision of values for control device efficiency.

The following guidelines were established:

1) All numbers not ending in .5 or .0, such as 92.3 or 76.6, have a precision of ± 0.1.

2) Numbers ending in .5, such as 75.5, have a precision of ± 0.3.

3) Numbers ending in .0 but not 0.0 or 5.0, such as 58.0, have a precision of ± 0.5.

4) Numbers less than 80 ending in 5.0, such as 55.0, have a precision of ± 5.0.

5) The numbers 85.0 and 95.0 have a precision of ± 2.5.

6) Numbers ending in 0.0, such as 50.0 or 90.0, have a precision of ± 5.0.

Statement 1) assumes that any number in this category must be fairly precise since it contains three significant figures. A properly conducted emission test yields values that are precise to the third significant figure.

Statement 2) consideres values ending in 0.5, which can possibly be accurate to three significant figures, but also can be the average of two numbers (such as 84 and 89). A precision factor of ± 0.3 represents a conservative approach.

Statement 3) suggests that these numbers, usually from control system manufacturer's literature, are precise to the nearest unit, or ± 0.5.

Statement 4) and 6) assume conservatively that the entry may have been a guess or that the literature source states values in increments of 5 or 10. Therefore these numbers are assigned a precision of ± 5.0.

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Statement 5) assumes that even though these numbers end in 5.0 and may have been determined by guess, entries of 80.0 or 90.0 would have preceded guesses of 85.0 and 95.0.

2.3 PRECISION OF THRUPUT VALUES

Instead of determining precision of a thruput value for each SCC, we assigned one precision to each major SCC category. Although the major categories include many different types of processes or fuels, the precisions are applied to the entire category.

A literature search was made to determine how specific industries in the major categories normally report their production or thruput. In addition, questionaires were completed by the Directors and Executive Committee of the Air Pollution Control Association. These questionaires provided estimates of typical thruput or production numbers for "average" installations in the major industries, along with the units and magnitudes in which the thruput or production is usually reported. With this information and engineering judgement, we developed precision values for thruput in each major SCC category.

The first major SCC category encompasses generation of electric power by burning of coal, gas, and oil. For various thruputs, X, the following precisions, P, were determined:

$$\begin{array}{rl} X \geq 200{,}000 & P = \pm\, 0.001 \\ 10{,}000 \leq X < 200{,}000 & P = \pm\, \frac{200}{X} \\ X < 10{,}000 & P = \pm\, 0.001 \end{array}$$

Numbers greater than 10,000 in this category represent coal usage in major power plants; the precisions therefore reflect the precision of coal thruput values. The precision of numbers reported in this range is approximately ± 200. Thruput values greater than 200,000 have precisions less than 0.001, but the precision value was rounded to 0.001 since the precisions of emission factors are given only to three decimal places. Thruput values less than 10,000 usually indicate gas and oil usage. Since the reported thruputs of these fuels are quite precise, on the order of $\frac{\pm 10}{10,000}$, a precision of ± 0.001 is specified.

Another major SCC category is industrial boilers, whose reported thruputs are assigned the following precision values:

$$X \geq 200,000 \qquad P = \pm 0.001$$

$$50,000 \leq X < 200,000 \qquad P = \pm \frac{500}{X}$$

$$1,000 \leq X < 50,000 \qquad P = \pm 0.020$$

$$X < 1,000 \qquad P = \pm 0.001$$

Again, the small thruputs are considered precise since they represent mainly gas, oil and small coal boilers. The consumption of gas and oil can be known and reported very precisely. As the thruput values increase, coal usage begins to dominate and the precisions reflect the change. Thruputs in the range of 1,000 to 50,000 have a precision of $\pm \frac{500}{25,000}$ or 0.020. Thruputs in the range of 50,000 to 200,000 are precise within ± 500. For very large thruputs, the values should be known and reported precisely. Thruputs in this range are also ± 500; rounding off

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to three decimal places gives a precision of ± 0.001. Two other major categories, commercial/institutional boilers and in-process fuel usage, are assigned the same thruput precision values as industrial boilers.

The precision of thruput values for all stationary internal combustion sources is ± 0.002. This value is based on engineering judgement and consideration that the thruput is likely to be small, but not necessarily reported to the same precision as thruput of industrial boilers. The fuel normally used is gas or oil and the thruput is reported with a precision of $\frac{\pm 1}{500}$ or $\frac{\pm 5}{2500}$, which equals ± 0.002.

The precision of thruputs for all chemical processes is estimated to be ± 0.010. The category of chemical manufacturing encompasses a wide variety of types of processes and a large range of thruputs. Although the thruput or production in these industries is likely to be known to a high degree of precision, many operators are reluctant to divulge precise production figures because of competition within the industry. It is assumed, therefore, that the precision to which thruput is generally reported is $\frac{\pm 10}{1000}$ for small operations, $\frac{\pm 1{,}000}{100{,}000}$ for medium-sized processes, and $\frac{\pm 10{,}000}{1{,}000{,}000}$ for large operations; these values yield an overall precision of ± 0.010.

The precision of thruput reported in the food/agricultural category is estimated to be 0.100. Again, the category encompasses a wide variety of types of processes and it is judged that the thruput values reported for these processes are not as precise as those of some other industries. Country elevators often report their thruput with a precision of $\frac{\pm 50,000}{500,000}$ bushels and terminal elevators report thruputs of about $\frac{\pm 1,000,000}{10,000,000}$ bushels. A precision of $\pm$ 0.100 is assigned to the entire food/agricultural category.

Precision of thruputs for metallurgical (primary and secondary) processes is specified as follows:

$$X \geq 500,000 \qquad P = \pm 0.001$$

$$50,000 \leq X < 500,000 \qquad P = \pm \frac{500}{X}$$

$$X < 50,000 \qquad P = \pm 0.010$$

Precision of thruput values for large metallurgical processes is judged to be good, and for small installations, not as good. Thruputs of the magnitude 50,000 to 500,000 are reported within $\pm$ 500. Thruputs larger than 500,000 are still within $\pm$ 500, but the precision for this category is rounded up to three decimal places, or 0.001. Thruputs less than 50,000 are as precise as those at 50,000. That is, thruputs of 25,000 have a precision of $\frac{\pm 250}{25,000}$ or + 0.010.

The precision of thruputs for mineral product installations follows a similar trend:

$$X \geq 1,000,000 \qquad P = \pm 0.001$$

$$50,000 \leq X < 100,000 \qquad P = \pm \frac{1000}{X}$$

$$10,000 \leq X < 50,000 \qquad P = \pm 0.020$$

$$X < 10,000 \qquad P = \pm 0.050$$

The large installations know and report their thruputs to a higher degree of precision than do the small ones. Thruputs greater than 50,000 are reported ±1000; precision of thruputs greater than 1,000,000 are rounded to 0.0001. Thruputs between 10,000 and 50,000 are generally reported with precisions in the range of $\frac{\pm 500}{25,000}$, or ± 0.020. Included among the small installations are seasonal rock crackers, for which the accounting of thruputs is not very precise, usually in the range of $\frac{\pm 250}{5,000}$ or ± 0.050.

Precision of thruput values for the petroleum industry is as follows:

$$\begin{array}{rl} X \geq 200{,}000 & P = \pm 0.001 \\ 1{,}000 \leq X < 200{,}000 & P = \pm \frac{200}{X} \\ X < 1{,}000 & P = \pm 0.002 \end{array}$$

This category includes both refinery operations and process heaters. Thruputs less than 1000 represent the process heaters, whereas the larger thruputs represent refining operations. The larger the refinery capacity, the more precisely the thruput is reported. This trend was determined from analysis of information presented in National Petroleum News Factbook Issue. Precisions given for thruputs greater than 1000 reflect the finding that the refinery capacities are generally reported ± 1000 barrels per day. The precision values take into account conversion from barrels per day to thousands of barrels per year. Precisions of thruput values for the process heaters are all on the order of 500 or ± 0.002.

Precisions of thruput values for the wood products industries are:

$$X \geq 10{,}000 \qquad P = \pm 0.010$$

$$X < 10{,}000 \qquad P = \pm 0.050$$

This category includes both paper pulping and sawmill operations. With a break point of 10,000, a precision of ± 0.010 represents mainly pulping operations and a precision of ± 0.050 represents various sawmill operations. Thruputs for pulping operations are generally reported with a precision of $\frac{\pm 5{,}000}{500{,}000}$ or ± 0.010. Thruputs for sawmill operations are generally reported in board-feet and are then converted to tons for entry on the NEDS form. This conversion entails some additional imprecision. The thruputs entered on the NEDS forms therefore are assigned a precision of approximately $\frac{\pm 250}{5{,}000}$ or ± 0.050.

The precision of thruput values for metal fabrication, leather products, textile manufacturing and "other/not classified" categories is estimated to be ± 0.050. These are small, diverse, and relatively low-polluting industries. It is estimated that the precision of thruput values reported by any of these industries would not be better than the precision of the smallest thruput reported in any of the other major categories. Therefore, the precision assigned to these categories is an average of the precisions of the smallest thruputs of the other categories.

The precision of thruput values for all point source evaporation operations is ± 0.010. This category includes petroleum

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storage and surface coating (i.e., painting) among others. The precision of +0.010 is valid of all thruputs in this category. For small thruputs, the precision is $\frac{\pm 10}{1000}$; for large thruputs the precision is $\frac{\pm 1,000}{100,000}$ or $\frac{\pm 10,000}{1,000,000}$. The precision of all these thruputs is ± 0.010.

The precision of thruput values for all solid waste disposal operations is estimated as follows:

$$X \geq 10,000 \qquad P = \pm 0.100$$
$$1,000 \leq X < 10,000 \qquad P = \pm 0.200$$
$$X < 1,000 \qquad P = \pm 0.500$$

Sources disposing of more than 10,000 tons per year usually are municipal incinerators, whose operations maintain records of the quantities burned. The precision of values for the amount burned is not very good, however, generally about $\frac{\pm 2,500}{25,000}$ or ± 0.100. Industrial and commercial incinerators burn less waste, and operators keep few, if any, records of the amount burned. Generally, the less waste incinerated, the less precise the thruput. Thruputs for industrial incinerators often range from 1,000 to 10,000, with an approximate precision of $\pm \frac{1,000}{5,000}$ or ± 0.200. Thruputs of smaller units (generally commercial units or small industrial incinerators) are often estimated when reported for NEDS purposes. The resulting precision is in the range of $\pm \frac{250}{500}$ or ± 0.500.

Precisions assigned to thruput values for all categories are summarized in Table 2.17.

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Table 2.17. PRECISION OF THRUPUT VALUES

SCC designation	Thruput, X	Precision, P
1 01 XXX XX	$X \geq 200,000$	$P = \pm 0.001$
(Electric generation)	$10,000 \leq X < 200,000$	$P = \pm \frac{200}{X}$
	$X < 10,000$	$P = \pm 0.001$
1 02 XXX XX	$X \geq 200,000$	$P = \pm 0.001$
(Industrial boilers)	$50,000 \leq X < 200,000$	$P = \pm \frac{500}{X}$
	$1,000 \leq X < 50,000$	$P = \pm 0.020$
	$X < 1,000$	$P = \pm 0.001$
1 03 XXX XX	$X \geq 200,000$	$P = \pm 0.001$
(Commercial/institutional boilers)	$50,000 \leq X < 200,000$	$P = \pm \frac{500}{X}$
	$1,000 \leq X < 50,000$	$P = \pm 0.020$
	$X < 1,000$	$P = \pm 0.001$
2 XX XXX XX (Internal Combustion engine)	All X	$P = \pm 0.002$
3 01 XXX XX (Chemical manufacture)	All X	$P = \pm 0.010$
3 02 XXX XX (Food/agricultural)	All X	$P = \pm 0.100$
3 03 XXX XX 3 04 XXX XX	$X \geq 500,000$	$P = \pm 0.001$
(Metallurgical)	$50,000 \leq X < 500,000$	$P = \pm \frac{500}{X}$
	$X < 50,000$	$P = \pm 0.010$
3 05 XXX XX	$X \geq 1,000,000$	$P = \pm 0.001$
(Mineral products)	$50,000 \leq X < 1,000,000$	$P = \pm \frac{1000}{X}$
	$10,000 \leq X < 50,000$	$P = \pm 0.020$
	$X < 10,000$	$P = \pm 0.050$

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Table 2.17 (Continued). PRECISION OF THRUPUT VALUES

SCC designation	Thruput, X	Precision, P
3 06 XXX XX (Petroleum industry)	$X \geq 200,000$	$P = \pm 0.001$
	$10,000 \leq X < 200,000$	$P = \pm \frac{200}{X}$
	$X < 10,000$	$P = \pm 0.001$
3 07 XXX XX (Wood products)	$X \geq 10,000$	$P = \pm 0.010$
	$X < 10,000$	$P = \pm 0.050$
3 09 XXX XX (Metal fabrication)	All X	$P = \pm 0.050$
3 20 XXX XX (Leather products)	All X	$P = \pm 0.050$
3 30 XXX XX (Textile manufacturing)	All X	$P = \pm 0.050$
3 90 XXX XX (Inprocess fuel)	$X \geq 200,000$	$P = \pm 0.001$
	$50,000 \leq X < 200,000$	$P = \pm \frac{500}{X}$
	$1,000 \leq X < 50,000$	$P = \pm 0.020$
	$X < 1,000$	$P = \pm 0.001$
3 99 XXX XX (Other/not classified)	All X	$P = \pm 0.050$
4 XX XXX XX (Point source evaporation)	All X	$P = \pm 0.010$
5 XX XXX XX (Solid waste disposal)	$X \geq 10,000$	$P = \pm 0.100$
	$1,000 \leq X < 10,000$	$P = \pm 0.200$
	$X < 1,000$	$P = \pm 0.500$

2.4 PRECISION OF VALUES FOR ASH AND SULFUR CONTENT OF FUEL

2.4.1 Anthracite and Bituminous Coal

Users of large quantities of coal periodically test the fuel's sulfur content by a procedure developed by the American Society for Testing Materials (ASTM). Even though the test procedure is relatively simple, results vary because of retention of sulfate sulfur in the ash and degree of precision with which the sample is weighed. The ASME Power Test Code for Solid Fuels, PTC 3.2-1954,[1] Par. 69 specifies that reproducibility of results of ash and sulfur content determinations shall be as follows:

Coal characteristics	Permissible differences when tested in different laboratories, absolute percent
TEST FOR ASH	
No carbonates present	0.3
Carbonates present	0.5
More than 12% ash, containing ing carbonate and pyrite	1.0
TEST FOR SULFUR	
Sulfur - under 2 percent	0.10
Sulfur - over 2 percent	0.20

Smith and Gruber report that the average ash content for coals from the major producing districts is always less than 12 percent and that two carbonate compounds occur frequently in coal. It is assumed that carbonates are present in all coals represented on the NEDS form. Precision of reported ash contents can then be expressed as follows:

Reported ash content	Precision
$\leq 12.0\ \%$	$\pm \frac{0.5}{\%\ A}$
$> 12.0\ \%$	$\pm \frac{1.0}{\%\ A}$

Precision of the reported sulfur contents of solid fuels can be expressed as follows:

Reported sulfur content	Precision
$< 2.0\ \%$	$\pm \frac{0.10}{\%\ S}$
$\geq 2.0\ \%$	$\pm \frac{0.20}{\%\ S}$

2.4.2 Distillate and Residual Oil

As with solid fuels, the ASTM specifies the testing of oils to determine sulfur content. The ASME Power Test Code for liquid fuels, PTC 3.1-1958[6] specifies reproducibility of results of sulfur content determination as follows:

Sulfur content, percent	Reproducibility by different operator and apparatus (absolute deviation from mean, percent)
0 to 0.5	0.03
over 0.5 to 1.0	0.04
over 1.0 to 2.0	0.05
over 2.0 to 3.0	0.07
over 3.0 to 4.0	0.09
over 4.0 to 5.0	0.12
over 5.0	0.14

The precision of reported contents of oils can be expressed by the following equation:

Reported sulfur content	Precision
$S \leq 0.5$	$\pm \frac{0.03}{\% S}$
$0.5 < S \leq 1.0$	$\pm \frac{0.04}{\% S}$
$1.0 < S \leq 2.0$	$\pm \frac{0.05}{\% S}$
$2.0 < S \leq 3.0$	$\pm \frac{0.07}{\% S}$
$3.0 < S \leq 4.0$	$\pm \frac{0.09}{\% S}$
$4.0 < S \leq 5.0$	$\pm \frac{0.12}{\% S}$
$S > 5.0$	$\pm \frac{0.14}{\% S}$

2.4.3 Liquefied Petroleum Gas

The standard method of test for total sulfur in fuel gases is specified per ASTM Designation D1072-56[2]. The absolute precision of this method as determined by ASTM is ± 0.1 grain of sulfur per cubic feet. This is equivalent to ± 0.0001 absolute percent sulfur by weight. The precision of any reported value of sulfur content (reported in percent on the NEDS form) is therefore:

$$\text{Precision} = \pm \frac{0.0001}{\% S}$$

3.0 PRECISION OF AREA SOURCE EMISSION VALUES

Emissions from area sources are calculated by use of the appropriate AP-42 emission factors and data entered on the NEDS area source coding form (Figure 3.1). In this section, the emission factors, categorized as non-automotive and automotive, and the NEDS input data entries are analyzed to determine the precision values.

3.1 PRECISION OF NON-AUTOMOTIVE AREA SOURCE EMISSION FACTORS

The area source emission factors used in the NEDS computer program are taken from AP-42. Where the area source emisison factor (or category) corresponds to a point source emission factor, the precision determined for the corresponding point source emission factor is also applied to the area source emission factor. Precisions of the area source emission factors are tabulated in Table 3.1.

3.1.1 Priority Pollutants

The priority area source pollutants (non-automotive) are particulate, SO_x, and NO_x from industrial combustion of bituminous coal, NO_x from commercial and institutional combustion of natural gas, HC from solvent evaporation and gasoline marketing, and HC and CO from off-highway gasoline usage.

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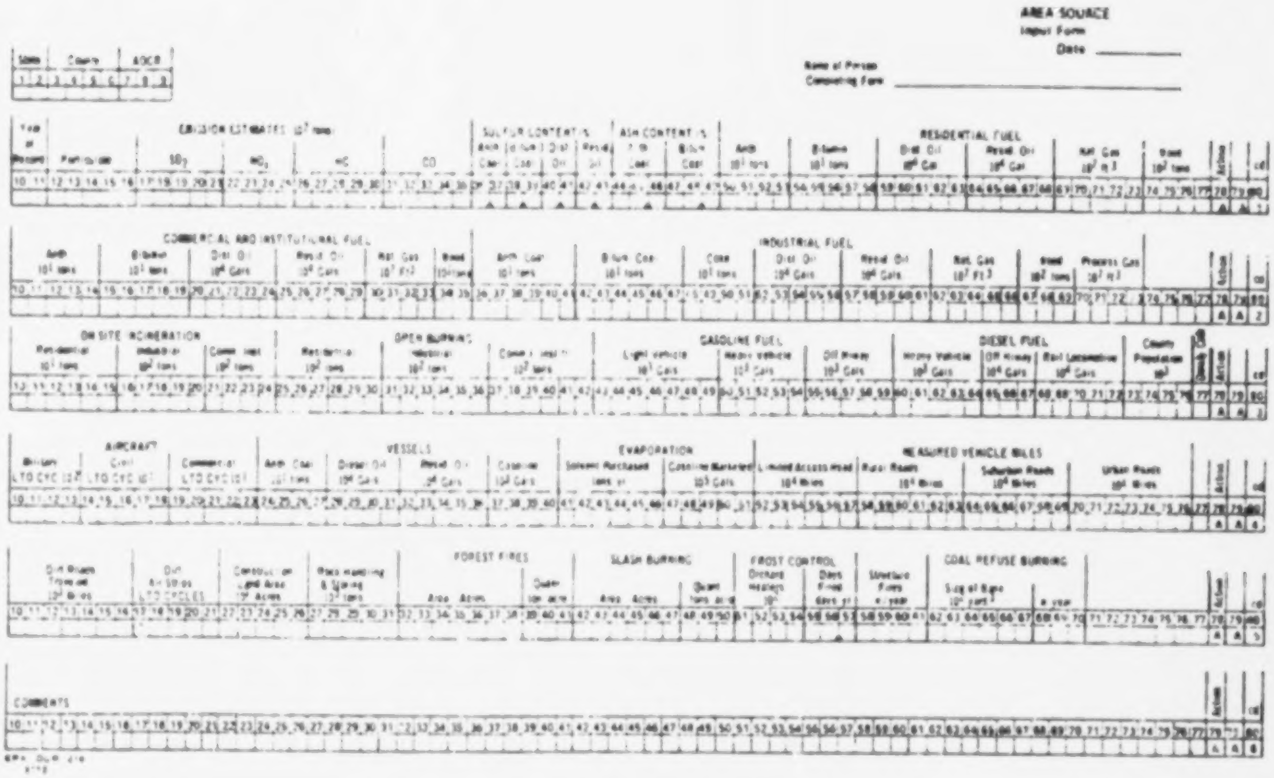

Figure 3.1. Area source coding form.

Table 3.1 PRECISION OF AREA SOURCE UNIT EMISSION FACTORS

Category	SCC number used	Pollutant				
		Particulate	SO_2	NO_x	HC	CO
Anthracite Coal						
Residential	10300109	0.211	0.146	0.172	0.237	0.357
Commercial/Inst.	10300109	0.211	0.146	0.172	0.237	0.357
Industrial	10300109	0.211	0.146	0.172	0.237	0.357
Bituminous Coal						
Residential	10300214	0.211	0.146	0.172	0.237	0.357
Commercial/Inst.	10300209 10300213	0.132	0.254	0.700	0.237	0.357
Industrial	10200209	0.132[a]	0.254[a]	0.700[a]	0.237	0.357
Distillate Oil						
Residential	10300503	0.211	0.146	0.172	0.237	0.357
Commercial/Inst.	10300502	0.211	0.146	0.172	0.237	0.357
Industrial	10200502	0.211	0.146	0.172	0.237	0.357
Residual Oil						
Residential	10200402	0.211	0.027	0.003	0.237	0.357
Commercial/Inst.	10200402	0.211	0.027	0.003	0.237	0.357
Industrial	10200402	0.211	0.027	0.003	0.237	0.357

a) Priority area source.

Table 3.1(Cont'd.) PRECISION OF AREA SOURCE UNIT EMISSION FACTORS

Category	SCC number used	Pollutant				
		Particulate	SO_2	NO_x	HC	CO
Natural Gas						
Residential	10300603	0.211	0.146	0.187	0.237	0.357
Commercial/Inst.	10300603	0.211	0.146	0.187	0.237	0.357
Industrial	10200602	0.211	0.146	0.391[a]	0.237	0.357
Wood - all categories	10200902	0.211	0.146	0.172	0.237	0.357
Process Gas-Indus.	10200602	0.211	0.146	0.391	0.237	0.357
On-Site Incineration						
Residential	50200102	0.211	0.146	0.172	0.237	0.357
Commercial	50200101 50200102	0.211	0.146	0.172	0.237	0.357
Industrial	502001 (01-02)	0.211	0.146	0.172	0.237	0.357
Open Burning						
Residential	50300202	0.211	0.146	0.172	0.237	0.357
Commercial	50300202	0.211	0.146	0.172	0.237	0.357
Industrial	50300202	0.211	0.146	0.172	0.237	0.357
Evaporation						
Solvent		--	--	--	0.000[a]	--

a) Priority area source.

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Table 3.1(Cont'd.) PRECISION OF AREA SOURCE UNIT EMISSION FACTORS

Category	SCC number used	Pollutant				
		Particulate	SO_2	NO_x	HC	CO
Evaporation (cont'd.)						
Gasoline marketing		--	--	--	0.921[a]	--
Dirt Roads		NYD	--	--	--	--
Dirt Airstrips		NYD	--	--	--	--
Construction		NYD	--	--	--	--
Rock Handling & Storage		NYD	--	--	--	--
Forest Fires		NYD	NYD	NYD	NYD	NYD
Slash Burning	50100202	0.208	--	0.172	0.237	0.357
Frost Control		NYD	NYD	NYD	NYD	NYD
Structure Fires		NYD	NYD	NYD	NYD	NYD
Coal Refuse Burning		NYD	NYD	NYD	NYD	NYD
Off Highway						
Gasoline		0.211	0.146	0.172	0.044[a]	0.028[a]
Diesel		0.211	0.146	0.172	0.237	0.357
Rail Locomotive		0.211	0.146	0.172	0.237	0.357

a) Priority area source.
NYD = Emission factor not yet defined.

Table 3.1(Cont'd.) PRECISION OF AREA SOURCE UNIT EMISSION FACTORS

Category	SCC number used	Pollutant				
		Particulate	SO_2	NO_x	HC	CO
Aircraft						
Military		0.211	0.146	0.172	0.237	0.357
Civil		0.211	0.146	0.172	0.237	0.357
Commercial		0.211	0.146	0.172	0.237	0.357
Vessels						
Bituminous coal		0.211	0.146	0.172	0.237	0.357
Distillate oil		0.211	0.146	0.172	0.237	0.357
Residual oil		0.211	0.146	0.172	0.237	0.357
Gasoline		0.211	0.146	0.172	0.237	0.357
Coke - Industrial		NYD	NYD	NYD	NYD	NYD

NYD = Emission factor not yet defined.

3.1.1.1 Area Source Combustion - The priority pollutants from area source combustion are also priority pollutants from point sources of combustion. Calculations determining the precision of the area source emission factors (as in the section on point source emission factors) are shown in Table 3.2.

3.1.1.2 Evaporation - The emission factor for solvent evaporation is 2000 lb/ton, which means that the amount of solvent purchased for a given operation is equal to the amount needed to make up evaporation losses. Therefore, any imprecision is entailed in the estimate of the amount of solvent purchased, and the emission factor of 2000 lb/ton is considered precise.

An AP-42 emission factor is given for HC from gasoline marketing. Since this is a priority area source emission factor, it is handled in the same manner as a priority point source emission factor. Calculation of precision of these factors is given in Table 3.2.

3.1.1.3 Off-Highway Gasoline Usage - Emission factors for off-highway gasoline usage are assumed to have been derived from factors for emissions from heavy-duty, gasoline-powered (HDG) highway vehicles. Using the HDG emission rates as the source of the emission factors for off-highway gasoline usage may affect the accuracy of the off-highway emission factors, but does not affect the precision. Therefore, the precision values for HDG emission rates are used in calculating the precision of off-highway gasoline emission factors.

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Table 3.2 PRIORITY NON-AUTOMOTIVE AREA SOURCE POLLUTANTS

Category	Pollutant	Emission factor, EF	No. of obs., n	Arith. mean, $\bar{x}$	St'd. dev. of obs., s_m	Coeff. of variation, C. V.	St'd. dev. of emission factor, S_f EF x C.V.	St'd. dev. of emission factor, E $S_f/\sqrt{n}$	Precision, P $\frac{E}{EF}$
Industrial bituminous coal combustion	Part[d]	13A	17	12.4A	6.77A	0.546	7.10A	1.72A	0.132
	SO_x[d]	38S	1	a		0.254	9.65S	9.65S	0.254
	NO_x[d]	15	0	a,c		0.700	10.5	10.5	0.700
Industrial natural gas combustion	NO_x[d]	180	4	296	232	0.784	141	70.5	0.391
Solvent evaporation loss (misc.)	HC	2000							0.000[e]
Gasoline marketing	HC	21 lb/10^3 gal.	0	a,c		0.921	19.4	19.4	0.921
Off-highway, gasoline	HC	553							0.044[f]
	CO	3030							0.028[f]

a) Where n is 1 or 0, average C.V., is used.
b) No reference available, emission factor is treated as one observation.
c) No observation found in references, emission factor is treated as one observation.
d) Also a priority point source pollutant.
e) Based on the assumption that all of the solvent evaporates.
f) Based on the precision of HDG emission factors.

Precision of emission factors for CO from off-highway gasoline usage is assumed to be equal to that of the emission factor for uncontrolled (pre-1970 model year) HDG exhaust. This precision value, discussed in detail in a later section on automotive factors (Section 3.3.2.1), is calculated as follows:

$$\text{Precision}_{CO} = \left[\frac{\text{Var }(C_i)}{(C_i)^2}\right]^{1/2} = [0.00081]^{1/2} = 0.028$$

The emission factor for HC from off-highway gasoline usage is calculated as the sum of the HC in uncontrolled HDG exhaust and combined HC emissions from crankcase and evaporation. Thus the variance of the off-highway HC emission rate is equal to the sum of the variances of the uncontrolled HDG exhaust and combined crankcase and evaporation HC emission rates:

$$\begin{aligned}\text{Var (Off-Highway HC)} &= \text{Var }(C_{HDG-HC}) + \text{Var }(f_{HDG-HC}) \\ &= 0.272 + 0.952 \\ &= 1.224\end{aligned}$$

The precision of the emission factor for HC from off-highway gasoline usage is therefore:

$$\text{Precision}_{HC} = \left[\frac{\text{Var(Off-Highway HC)}}{(C_{HDG-HC} + f_{HDG-HC})^2}\right]^{1/2} = \left[\frac{1.224}{(17 + 8.2)^2}\right]^{1/2} = 0.044$$

3.1.2 Non-Priority Pollutants

Emission factors for all other area sources are given the precision of the corresponding point source emission factor. When there is no corresponding point source emission factor, the area source is assigned the average precision that was determined for point source emission factors. Precision values are given in Table 3.1.

3.2 PRECISION OF AREA SOURCE CODING FORM ENTRIES

The purpose of this section is to define a precision for every entry on the NEDS area source coding form, excluding the emission estimates. The coding form and the entries are discussed in detail in EPA's "Guide for Compiling a Comprehensive Emission Inventory"[7], published as APTD-1135. When used in conjunction with the precision ratings of the emission factors, the precision values for NEDS entries will define a quality rating of the area source emission values in an emission inventory.

For all entries on the area source coding form, the method of determination is assumed to be correct. The precision of the entry is then dependent on the precisions of the factors used to determine the entry. For instance, if an entry X is a function of factors A, B, and C according to the equation:

$X = (A)(B)(C)$ then the precision of X (P_x) is a function of the precisions of the individual factors as follows:

$$P_x = \sqrt{P_a^2 + P_b^2 + P_c^2}$$

For the cases in which APTD-1135 provides several methods for determining a single entry, precisions are

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calculated only for the method believed to be most widely used. For a factor whose precision varies over a wide range of values dependent on the size of the factor, a median value is used in determining precision.

All entries entail rounding errors. The units of each information field on the coding form define what rounding off, if any, must be performed. For example, if values to be entered in a field are expressed in units of 10^4 gallons, the entry should be considered precise within ± 5 x 10^3 gallons. In addition to the rounding errors, the precision of the data-gathering techniques must be considered. When the precision of data-gathering techniques is zero, the precision of rounding is used. When a precision other than zero is assigned to the data-gathering techniques, that precision is used for the entry on the coding form.

Precisions of entries on the NEDS area source coding form are summarized in Table 3.3.

3.2.1 County Data

3.2.1.1 Population - County population figures are obtained from the 1970 Census of Population.[8] The Bureau of Census reports almost complete coverage in the 1970 census. They report the population to an exact number, much more precise than the nearest thousand coded on the NEDS form. The precision therefore depends only on the significant figures reported. For this field the precision equals ±500 divided by the entry.

Table 3.3 SUMMARY OF THE PRECISIONS OF ENTRIES
ON THE NEDS AREA SOURCE CODING FORM

Card	Columns	Precision of entry	Comments
1	50-53	+0.196	(for a zero in Card 1, Columns 54-58)
		+0.045	(for an entry or blank in Card 1, Columns 54-58)
1	54-58	+0.196	(for a zero in Card 1, Columns 50-53)
		+0.045	(for an entry or blank in Card 1, Columns 50-53)
1	59-63	+0.104	
1	64-68	+0.144	
1	69-73	+0.054	
1	74-77	+0.555	
2	10-14	+0.615	(for a zero in Card 2, Columns 36-41)
		+0.637	(for an entry or blank in Card 2, Columns 36-41)
2	15-19	+0.294	
2	20-24	+0.312	
2	25-29	+0.144	
2	30-33	+0.050	
2	34-35	+0.269	
2	36-41	+0.664	
2	42-47	$+1.26 \times 10^{2}$ (entry)$^{-.97}$	
2	48-51	+0.150	
2	52-56	+0.023	
2	57-61	+0.023	
2	62-66	+0.127	
2	67-69	+0.250	
2	70-73	+0.200	
3	10-15	+10.00	
3	16-20	+10.00	
3	21-24	+10.00	
3	25-30	+10.00	
3	31-36	+10.00	

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Table 3.3 (continued). SUMMARY OF THE PRECISION OF ENTRIES ON THE NEDS AREA SOURCE CODING FORM

Card	Columns	Precision of entry	Comments
3	37-42	±10.000	
3	43-49	± 0.045	(for an entry in Card 4, Columns 52-76) Variable G_1
		± 0.071	(for no entry in Card 4, Columns 52-76) Variable G_1
3	50-54	± 0.045	(for an entry in Card 4, Columns 52-76) Variable G_2
		± 0.072	(for no entry in Card 4, Columns 52-76) Variable G_2
3	55-59	$\frac{[0.022T^2 - .572\ TP + 28.73\ P^2]^{1/2}}{T}$	
		where T = entry in Card 3, Columns 55-59, and P = entry in Card 3, Columns 73-76	
3	60-64	$\pm \frac{0.5}{\text{entry}}$	Variable G_3
3	65-67	± 0.082	
3	68-72	± 0.100	
3	73-76	$\pm \frac{500}{\text{entry}}$	
3	77	precise number, p = 0.000	Variables P_u and P_R
4	10-13	$\pm \frac{0.5}{\text{entry}}$	
4	14-18	$\pm \frac{0.5}{\text{entry}}$	
4	19-23	$\pm \frac{0.5}{\text{entry}}$	
4	24-27	± 0.030	
4	28-31	± 0.130	
4	32-36	± 0.180	
4	37-40	± 0.158	
4	41-46	for the entry in Card 3, Columns 73-76 in the range: 0 to 100....................±0.936 100 to 500....................±0.484 500 to 1000....................±0.246 1000 to 9999....................±0.165	

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Table 3.3 (continued). SUMMARY OF THE PRECISION OF ENTRIES ON THE NEDS AREA SOURCE CODING FORM

Card	Columns	Precision of entry	Comments
4	47-51	± 0.060	
4	52-57	± 0.032	Variable M_1
4	58-63	± 0.032	Variable M_2
4	64-69	± 0.032	Variable M_3
4	70-76	± 0.032	Variable M_4
5	10-16	± 0.503	
5	17-21	± 0.000	
5	22-26	$\pm \frac{0.5}{\text{entry}}$	
5	27-31	$\pm \frac{0.5}{\text{entry}}$	
5	32-38	± 0.050	
5	39-41	± 0.150	
5	42-47	$\pm \frac{50}{\text{entry}}$	
5	48-50	± 0.250	
5	51-54	$\pm \frac{0.5}{\text{entry}}$	Position 385-388
5	55-57	$\pm \frac{5.0}{\text{entry}}$	Position 389-391
5	58-61	$\pm \frac{5.0}{\text{entry}}$	
5	62-67	± 0.270	
5	68-70	precise number, p = 0.000	

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3.2.1.2 Density Code - The 1970 census also classifies urban and rural populations in a county as a percentage urban. This percentage is precise based on the classification specified by the Bureau of Census. Since APTD-1135[7] defines a code for each percentage, no variation is introduced, and the density code is a precise number.

3.2.2 Sulfur Content

APTD-1135[7] specifies using a weighted average for sulfur content of fuels consumed in a county. This averaging creates serious problems in determining precision. To simplify the determination, assume that fuels consumed by different categories of users have the same sulfur content countywide. This is a logical assumption, since most coal used in a given area is mined from the same general region.

3.2.2.1 Anthracite and Bituminous Coal - The precision of tests for determining sulfur content of coal is discussed in Section 2.4.1, which specifies that precisions of the sulfur content of solid fuels can be expressed as follows:

Reported sulfur content	Precision
$< 2.0\%$	$\pm \frac{0.10}{\%S}$
$\geq 2.0\%$	$\pm \frac{0.20}{\%S}$

3.2.2.2 Distillate and Residual Oil - The precision of tests for determining sulfur content of fuel oil is discussed in Section 2.4.2. Precisions of the sulfur content of fuel oil can be expressed as follows:

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Reported sulfur content	Precision
$S \le 0.5$	$\pm \frac{0.03}{\% S}$
$0.5 < S \le 1.0$	$\pm \frac{0.04}{\% S}$
$1.0 < S \le 2.0$	$\pm \frac{0.05}{\% S}$
$2.0 < S \le 3.0$	$\pm \frac{0.07}{\% S}$
$3.0 < S \le 4.0$	$\pm \frac{0.09}{\% S}$
$4.0 < S \le 5.0$	$\pm \frac{0.12}{\% S}$
$S > 5.0$	$\pm \frac{0.14}{\% S}$

3.2.3 Ash Content

Again, APTD-1135[7] specifies using a weighted average to determine ash content of coals over an entire county. In this case, also, assume that the ash content is constant over the county. The ash contents for anthracite and bituminous coal are determined in the same manner if ASTM procedures are followed, as discussed in Section 2.4.1. Accordingly, precision of the ash content value reported on the NEDS form may be expressed as follows:

Reported ash content	Precision
$\le 12.0\%$	$\pm \frac{0.5}{\% A}$
$> 12.0\%$	$\pm \frac{1.0}{\% A}$

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3.2.4 Residential Fuel

For most fuels, residential fuel usage is determined by apportioning statewide fuel totals to residential categories and then apportioning the residential categories to counties on the basis of dwelling units per county heating with the fuel.

3.2.4.1 Anthracite Coal - Residential consumption of anthracite is usually determined on the basis of the number of dwelling units heating with coal as enumerated by the 1970 Census of Housing.[9] The average consumption per dwelling unit is the product of the coal heating requirement factor[7], the average annual heating degree-days from Local Climatological Data[10], and a correction factor for the median number of rooms per dwelling unit in the county versus the national median of 5.0 rooms per dwelling unit.[9] The calculated residential usage of coal must be compared with the statewide area source totals, determined by subtracting the point source consumption of anthracite from the total state consumption of anthracite given by the Bureau of Mines.[11] If the calculated residential usage of coal should exceed the statewide area source usage of anthracite, consider the statewide usage as the residential consumption of anthracite. Assume that the difference between the calculated residential usage of coal and the area source consumption of anthracite represents the residential consumption of bituminous coal. The precision of the entry for

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residential consumption of anthracite coal will depend on precisions of the factors used in the determination.

Number of dwelling units heating with coal - This figure is obtained from the 1970 Census of Housing[9] under "House Heating Fuel". This source gives a county-by-county enumeration of houses heated with various types of fuel. The figure is obtained from a 5 percent sample of all the housing units nationwide. The Census of Housing provides tables for calculation of the approximate standard error based on the percent sampled and the number of housing units in the area. Since the standard error varies from county to county, we generalize a precision value based on data from the states of Ohio, Michigan, Kentucky, and Iowa. See Appendix A.

precision = ± 0.14

Coal heating requirement factor - This factor represents the coal required to heat an average 5-room dwelling for one degree-day. The factor cited in APTD-1135 is 0.0012 ton coal per dwelling unit per degree-day. Calculating by the method in Appendix B we obtain:

Type House	Factor
Insulated	0.001097 ton coal/D.U.-D.D.
Non-insulated	0.00161 ton coal/D.U.-D.D.

Analysis based on these values indicates that the factor cited in APTD-1135 was derived by assuming that 80 percent of households heating with anthracite coal are insulated.

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Factor = 0.8 (.001097) + 0.2 (.00161) = 0.0012

Assume that 66.7 percent of the values occur in the range from 100 percent insulated to 60 percent insulated and that this range represents two standard deviation units.

	Factor
100% insulated	0.001097
60% insulated	0.0013022

$$\text{standard deviation} = \frac{0.0013022 - 0.001097}{2} = 0.0001026$$

$$\text{precision} = \frac{0.0001026}{0.0012} = \pm 0.084$$

Annual heating degree-days - Degree-days are obtained from local meteorological data on average 24-hour temperatures by defining a degree-day as a day where the average 24-hour temperature is 1 degree below 65°F. Temperature may be measured very precisely. Considering a 0.5-degree error in the significant range of 10 degrees or greater below 65°, we get a maximum error of ± 0.05.

Correction factor for number of rooms per dwelling unit in the study area - This factor is based on a 20 percent sample of all households and therefore should be precise within the limits of the reported units. Since this value is reported to the nearest tenth, rounding off errors would give ± 0.05 or less. The precision would then be $\pm \frac{0.05}{5}$. The 5.0 in the denominator is a precise figure since it is the basis for calculation of heat loss. Therefore, precision = ± 0.01.

Total statewide area source consumption of anthracite coal - The precision of this factor depends on the precision

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of the state consumption totals in Minerals Yearbook[11] and the precision of the state point source totals. The state totals are reported to the nearest ton and at least four significant figures. Consider this as a precise number, since the worst case is precise within + 0.0001. The reported point source consumption is based on information from each point source. The precision depends on the number of significant figures reported. Most point sources report at least three significant figures. Assuming this is the case, the precision equals $\pm \frac{0.5}{100} = \pm 0.005$. Assuming that the point source total accounts for no more than 90 percent of the state totals, the precision of the area source totals is ± 0.045.

Overall precisions - Two cases must be considered in determining the overall precision of the anthracite coal entry.

Case 1: Anthracite coal is the only coal used as residential fuel (a zero will appear for residential bituminous coal consumption). The consumption of anthracite is the product of the factors developed above. Overall precision (P_o) is determined as follows:

$$P_o^2 = P_1^2 + P_2^2 + P_3^2 + P_4^2$$

$$P_o^2 = (0.17)^2 + (0.084)^2 + (0.05)^2 + (0.01)^2$$

$$P_o^2 = 0.03856$$

$$P_o = \pm 0.196$$

Case 2: Both anthracite and bituminous coals are used by residential sources. In this case the residential anthracite consumption equals the difference between the Bureau of Mines figure and the point source totals. This precision, calculated above, equals ± 0.045.

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3.2.4.2 Bituminous Coal - Essentially the same procedures and factors are used for calculating residential consumption of bituminous coal as for calculating residential consumption of anthracite coal; the same precisions apply. Two cases are considered for bituminous coal:

Case 1: Bituminous coal is the only coal used as residential fuel (a zero will appear for residential anthracite coal consumption. This total is determined by the product of the factors defined in Section 3.2.4.1. The precision will be the same as determined for Case 1 in Section 3.2.4.1 and equals ± 0.196.

Case 2: Both anthracite and bituminous coal are consumed by residential sources. The figure is calculated by determining total coal usage and subtracting the total area source consumption of anthracite (assuming only residential sources). The precision is dependent on the factors in Section 3.2.4.1, but since a subtraction is involved, an assumption must be made as to the contribution from each factor. The equation used to determine bituminous coal usage is:

$$B = T - A$$

where B = bituminous coal usage

A = anthracite coal usage

T = total coal usage

From Section 3.2.4.1 the precision of $T = \pm 0.196$ and

the precision of $A = \pm 0.045$

If it is assumed that anthracite consumption accounts for no more than 80 percent of the total coal consumption ($A \leq 0.8T$), the maximum error possible would be:

$$\pm 0.196T \pm 0.045\ (0.8T)$$

or $\pm 0.241T$

The precision of B, based on the maximum error and $B \pm 0.2T$, is

$$\pm \frac{0.241T}{0.2T} = \pm 1.205$$

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3.2.4.3 Distillate Oil - Residential consumption of distillate oil is determined by the same procedures outlined with regard to anthracite coal. The only factors that differ are the number of dwelling units heating with fuel oil and the oil heating requirement factor.

Number of dwelling units heating with fuel oil - This figure is obtained by the same procedure outlined for anthracite coal calculations. The calculation of standard error is based on a generalization of data from Ohio, Michigan, Kentucky, and Iowa, as in Appendix A.

precision = ± 0.06

Oil heating requirement factor - This factor represents the amount of oil required to heat an average 5-room dwelling for 1 degree-day. The value is given as 0.18 gallon oil per dwelling unit per degree-day. According to Appendix B (ASHRAE Handbook values):

Type House	Factor
Insulated	0.16847 gal oil/D.U.-D.D.
Non-insulated	0.26578 gal oil/D.U.-D.D.

Most oil-heated homes are insulated; upon analysis, the factor appears to represent a distribution of 88 percent insulated and 12 percent non-insulated homes. Since we have no data on the actual ratio of insulated to non-insulated homes for different counties, an assumption must be made. If we assume that for 68 percent of the counties the range is 75 to 100 percent insulated homes and that this range represents two standard deviation units, we get:

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	Factor
100% insulated	0.16847
75% insulated	0.1927975

$$\text{standard deviation} = \frac{0.1927975 - 0.16847}{2} = 0.0122$$

$$\text{precision} = \frac{0.0122}{0.18} = \pm\ 0.068$$

Overall precision - Precision of the value for residential consumption of distillate oil is equal to the product of precisions of the factors for degree-days (0.05) and rooms-per-dwelling (0.01, both from Section 3.2.4.1) and the factors for number of dwelling units heating with distillate oil and oil heating requirements as just calculated. The precision is then:

$$P_o^{\ 2} = (0.05)^2 + (0.01)^2 + (0.06)^2 + (0.068)^2$$

$$P_o^{\ 2} = 0.010824$$

$$P_o = \pm\ 0.104$$

3.2.4.4 Residual Oil - Residual oil is not usually burned in residential furnaces. If it is used within the area of the inventory, however, contact the local fuel dealers to determine what percentage of their customers are sold residual oil. The percentage is applied to the total amount of oil consumed by residential users (with precision of 0.104, determined above) to calculate gallons of residual oil. Assume that the dealers are precise within 10 percent when reporting the distribution of oil. Precision of the value for residual oilconsumption is then determined as follows:

$$P_o^2 = (0.104)^2 + (0.10)^2$$

$$P_o^2 = 0.020816$$

$$P_o = \pm 0.144$$

3.2.4.5 Natural Gas - Natural gas consumption by residential users is reported by state in Reference 13. The Bureau of Mines states that these reports are obtained by direct contact with dealers and others; they assert that these contacts account for 80 percent of the gas produced and that most of the remaining gas is accounted for in marketing reports of the companies contacted. The statewide totals are apportioned to the county by the ratio of county/state dwelling units heating with natural gas. If we assume that the Bureau of Mines statement implies that at least three-fourths of the remaining 20 percent of natural gas usage is accounted for, then the precision of the value for residential natural gas consumption per state is ± 5 percent. The precision of the number of dwelling units per county heating with natural gas, calculated according to Appendix A, is ± 0.02. The precision of the number of dwelling units per state heating with natural gas is also calculated according to Appendix A by using the average number of dwelling units per state and consulting Reference 10. The precision is ± 0.001. The overall precision is then:

$$P_o^2 = (0.05)^2 + (0.02)^2 + (0.001)^2$$

$$P_o^2 = 0.002901$$

$$P_o = \pm 0.054$$

3.2.2.6 Wood - The procedures outlined with regard to anthracite coal consumption are used again in determining residential consumption of wood. The two factors that differ are the number of dwelling units heating with wood and the wood requirement factor.

Number of dwelling units heating with wood - This figure is obtained by the same procedure used earlier for other fuels. The calculation of standard error is based on a generalization of data from Ohio, Michigan, Kentucky, and Iowa, as in Appendix A.

$$\text{precision} = \pm\ 0.42$$

Wood heating requirement factor - This factor represents the wood required to heat an average 5-room dwelling for 1 degree-day. The value given in APTD-1135 is 0.0017 ton of wood per dwelling unit per degree-day. According to Appendix B (ASHRAE Handbook values):

Type House	Factor
Insulated	0.00189 ton wood/D.U.-D.D.
Non-insulated	0.00286 ton wood/D.U.-D.D.

These factors are higher than that given in APTD-1135. If it is assumed that the APTD value is the result of two observations, the precision may be calculated:

$$\sigma' = \frac{0.00286 - 0.00189}{1.13} = 8.6 \times 10^{-4}$$

$$\sigma_{\overline{x}} = \frac{8.6 \times 10^{-4}}{\sqrt{2}} = 6.1 \times 10^{-4}$$

$$\text{precision} = \frac{6.1 \times 10^{-4}}{0.0017} = \pm\ 0.358$$

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Overall precision - Precision of the value for residential consumption of wood is equal to the product of precisions of the factors for degree-days (0.05) and rooms-per-dwelling (0.01, both from Section 3.2.4.1) and the factors for number of dwelling units heating with wood and wood heating requirements, as just calculated. The precision is then:

$$P_o^2 = (0.05)^2 + (0.01)^2 + (0.42)^2 + (0.358)^2$$

$$P_o^2 = 0.3072$$

$$P_o = \pm 0.554$$

3.2.5 Commercial and Institutional Fuel

For most fuels, commercial and institutional use is determined by obtaining statewide totals from Bureau of Mines publications and apportioning to county on the basis of population.

3.2.5.1 Anthracite Coal - Commercial-institutional use of anthracite coal is determined by subtracting statewide residential use of anthracite from the total statewide area source consumption of anthracite and apportioning the balance to county on the basis of population. The precisions of the values for statewide residential consumption and total area source consumption of anthracite were determined in Section 3.2.3.4. Also, the precisions for county and state population figures were determined earlier, and both are precise values. The overall precision is then the

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precision of the number representing the difference between residential usage and total area source usage. Assuming that residential sources consume 75 percent of the anthracite, the precision is determined as follows:

$$T = A - R$$

where T = commercial-institutional consumption of anthracite

A = total area source consumption of anthracite

R = residential consumption of anthracite

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{\mathrm{Var}\ (A) + \mathrm{Var}\ (R)}{(A - R)^2}$$

$$\mathrm{Var}\ (A) = (0.045A)^2$$

$$\mathrm{Var}\ (R) = (0.196)^2$$

$$\text{but } R = 0.75A$$

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{(0.045A)^2 + (0.147A)^2}{(A - 0.75A)^2}$$

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{0.0236A^2}{0.0625A^2}$$

$$\frac{\sigma\ (T)}{T} = \frac{0.154A}{0.25A}$$

$$\text{but } 0.25A = T$$

$$\text{therefore} \quad \frac{\sigma\ (T)}{T} = \frac{0.154\ (4T)}{T}$$

$$\text{precision} = \underline{+}\ 0.615$$

This precision value applies only to cases where no anthracite is consumed by industrial sources. For cases where anthracite is consumed by industrial sources, first subtract statewide residential usage from total area source usage, then assign 60 percent of that balance to the commercial-institutional category and 40 percent to the industrial category. Multiplying by 60 percent reduces the precision of the entry. Assuming that 60 percent is precise within 10 percent gives an overall precision as follows:

$$P_o^2 = (P_1)^2 + (\frac{10}{60})^2$$

$$P_o^2 = (0.615)^2 + (0.167)^2$$

$$P_o^2 = 0.4061$$

$$P_o = \pm 0.637$$

3.2.5.2 Bituminous Coal - The value for commercial-institutional consumption of bituminous coal is the difference between the Bureau of Mines figure for statewide consumption of bituminous coal (obtained from retail dealers) and the residential consumption of bituminous coal, apportioned to counties on the basis of population.

The Bureau of Mines figure represents almost complete coverage of coal producers. The figure should be precise within the nearest thousand tons as reported. The error would be ± 500 tons. Based on a median value of 193 thousand tons for retail dealers distribution of bituminous coal in the state, the precision equals 193,000 or ± 0.003. The precision of the population figures is zero (Section 3.2.1). The precision of the value for residential usage of bituminous coal has also been determined; assuming no anthracite

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coal consumption, it is ± 0.196. The overall precision is dependent on precision of the percentage of coal consumed by residential sources. Assuming that residential consumption represents 60 percent of the retail dealers figure gives the following precision:

$$T = D - R$$

where T = commercial-institutional consumption of bituminous coal

D = retail dealers figure from Bureau of Mines

R = residential consumption of bituminous coal

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{\mathrm{Var}\ (D) + \mathrm{Var}\ (R)}{(D - R)^2}$$

$$\text{but } R = 0.6D$$

$$\mathrm{Var}\ (D) = (0.002D)^2$$

$$\mathrm{Var}\ (R) = (0.196)^2 = (0.1176D)^2$$

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{(0.002D)^2 + (0.1176D)^2}{(0.4D)^2}$$

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{0.01383376D^2}{0.16D^2}$$

$$\text{precision} = \frac{\sigma\ (T)}{T} = \pm\ 0.294$$

3.2.5.3 Distillate Oil - Commercial and institutional distillate oil consumption is the difference between residential consumption and the sum of the figures given for "distillate-type heating oils", "kerosene used for heating", and "distillate used by the military" from Tables 5, 6, and 12 of Reference 12. The difference is then apportioned to county on the basis of population.

The Bureau of Mines totals represent essentially complete coverage of oil producers. The figures should be precise within the nearest thousand barrels for each category. The median values for each category are 532,000 barrels "kerosene used for heating"; 3,339,000 barrels - "distillate-type heating oils"; and 96,000 barrels - "distillate used by the military." Assuming the maximum error equal to the standard deviation in each case, the precision is calculated.

$$T = K + D + M_d$$

where T = total use of distillate for heating

K = kerosene used for heating

D = distillate-type heating oils

M_d = distillate used by the military

$\sigma\ (K) = \pm\ 500$ barrels

$\sigma\ (D) = \pm\ 500$ barrels

$\sigma\ (M) = \pm\ 500$ barrels

$$\frac{\text{Var}\ (T)}{T^2} = \frac{\text{Var}\ (K) + \text{Var}\ (D) + \text{Var}\ (M_d)}{(K + D + M)^2}$$

$$\frac{\text{Var}\ (T)}{T^2} = \frac{3(500)^2}{(T^2)}$$

$$\text{Var}\ (T) = 750{,}000$$

$$\sigma\ (T) = 866$$

$$\frac{\sigma\ (T)}{T} = \frac{866}{(3{,}339{,}000 + 96{,}000 + 532{,}000)}$$

$$\text{precision} = \frac{\sigma (T)}{T} = \pm\ 0.0002$$

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For most cases the totals are essentially precise figures. Imprecision is introduced in determining the difference between the totals and residential consumption. Assuming that residential sources account for 75 percent of the distillate used for heating, the precision is calculated as follows:

$$C - I = T - R$$

$C - I$ = commercial-institutional area source consumption of distillate oil

T = distillate oil-total area source consumption

R = residential consumption of distillate oil

$$\frac{\mathrm{Var}\ (C - I)}{(C - I)^2} = \frac{\mathrm{Var}\ (T) + \mathrm{Var}\ (R)}{(T - R)^2}$$

$$\sigma\ (R) = 0.104R \text{ (Section 3.2.4.3)}$$

$$R = 0.75T$$

$$\frac{\mathrm{Var}\ (C - I)}{(C - I)^2} = \frac{(0.0002T)^2 + (0.08T)^2}{(0.25T)^2}$$

$$\frac{\mathrm{Var}\ (C - I)}{(C - I)^2} = \frac{0.00000004 + 0.0061}{0.0625}$$

$$\frac{\mathrm{Var}\ (C - I)}{(C - I)^2} = 0.097$$

$$\frac{\sigma\ (C - I)}{(C - I)} = 0.312$$

Apportionment to county on the basis of population adds no imprecision, therefore

precision = ± 0.312

3.2.5.4 Residual Oil - The value for commercial and institutional usage of residual oil is the difference between the amount of residential consumption and the sum of the figures

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given for "residual-type heating oils" and "residual used by the military" from Tables 7 and 12 of Reference 12. The difference is then apportioned to counties on the basis of population.

As mentioned earlier, the Bureau of Mines figures should be precise within ± 500 barrels for each category. The median values for each category are 561,000 barrels - "residual-type heating oils" and 103,000 barrels - "residual used by the military." Assuming that the maximum error is equal to the standard deviation in each case, the precision is calculated:

$$T = R + M_R$$

where T = total residual used for heating

R = "residual-type heating oils"

M_R = "residual used by the military"

$$\frac{\text{Var }(T)}{T^2} = \frac{\text{Var }R + \text{Var }M_R}{(R + M_R)^2}$$

$$\frac{\text{Var }(T)}{T^2} = \frac{2(500)^2}{T^2}$$

$$\text{Var }(T) = 500{,}000$$

$$\sigma\ (T) = 707$$

$$\frac{\sigma\ (T)}{T} = \frac{707}{(561{,}000 + 103{,}000)}$$

$$\frac{\sigma\ (T)}{T} = .0011$$

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Again calculation of the residential consumption of residual oil introduces imprecision into the totals for commercial-institutional consumption. Assuming that residential sources account for 50 percent of the residual used for heating, the precision is calculated as follows:

$$C - I = T - A_R$$

C - I - commercial-institutional consumption of residual oil by area sources

T = residual oil - total area source consumption

A_R = residential consumption of residual oil

$$\frac{\text{Var } (C - I)}{(C - I)^2} = \frac{\text{Var } (T) + \text{Var } (A_R)}{(T - A_R)^2}$$

$\sigma\ (A_R) = 0.144A_R$ (Section 3.2.4.4)

$A_R = 0.5T$

$$\frac{\text{Var } (C - I)}{(C - I)^2} = \frac{(0.0011T)^2 + (0.072T)^2}{(0.5T)^2}$$

$$\frac{\text{Var } (C - I)}{(C - I)^2} = \frac{0.00000121 + 0.005184}{0.25}$$

$$\frac{\text{Var } (C - I)}{(C - I)^2} = 0.02074$$

$$\frac{\sigma\ (C - I)}{C - I} = 0.144$$

precision = $\pm$ 0.144

3.2.5.5 Natural Gas - Commercial-institutional usage of natural gas is the sum of values given for "commercial" and

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"other users" in Table 6 of Reference 13. The total is apportioned to counties on the basis of population.

The Bureau of Mines figures should be precise within ± 5 percent. Apportioning to counties on the basis of population should add no imprecision. Therefore, the overall precision is ± 0.05.

3.2.5.6 Wood - A figure for commercial-institutional consumption of wood can be entered only if adequate local data from fuel dealers or other reliable sources are available. Quantities of wood are usually reported in units of cords. Since cords measure volume rather than weight, any variability in density of the wood would affect the precision of the weight reported. Reference 22 reports that densities of wood vary by more than 20 pounds per cubic foot. Assuming that the wood in a given location differs by only 10 pounds from an average density of 40 pounds per cubic foot gives a precision equal to $\frac{10}{40}$ or ± 0 25. The quantity of wood reported also entails imprecision. Fuel dealers should give figures precise within 10 percent. The overall precision of the value for commercial-institutional consumption of wood is then:

$$P_o{}^2 = (0.25)^2 + (0.10)^2$$

$$P_o{}^2 = 0.0725$$

$$P_o = \pm 0.269$$

3.2.6 Industrial Fuel

For most categories, usage of industrial fuel by area sources is calculated by subtracting state totals for point

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source consumption from Bureau of Mines data and apportioning the balance to counties according to a ratio of the number of manufacturing employees in the county to the total number of manufacturing employees in the state.

3.2.6.1 Anthracite Coal - The total consumption of anthracite coal by industrial users per state is determined in the same manner as consumption by commercial-institutional users except that the factor for industrial usage is 40 percent rather than 60. The total is then apportioned to counties on the basis of the total number of manufacturing employees per county.

Industrial area source consumption of anthracite per state - Precision of this figure is calculated in the same way as the value for commercial-institutional usage with the exception of the 40 percent factor:

$$P^2 = (0.615)^2 + (\frac{10}{40})^2$$

$$P^2 = 0.4407$$

$$P = \pm 0.664$$

Number of manufacturing employees - This figure is obtained for county and state from Bureau of Census data (Reference 15). This census encompassed all establishments employing one or more persons during the census year (1967) and thus includes all sources considered as industrial in the scope of the NEDS system. Since an industrial firm can accurately report the number of employees, and since all firms were contacted, the census figure should be accurate.

But the Census Bureau reports employees to the nearest hundred, leading to a maximum error in the county total of ± 50 employees. If we assume that the error is random, the state total will also have a maximum error of ± 50 employees. Because of the variability of numbers of employees in different counties and states, we assume that the precision of median values will apply to all cases. The median value for a state is 175,000 employees. The precision of this value is $\frac{50}{175,000}$ or ± 0.0003. The median value for a county is 2150 employees. The precision of this value is $\frac{50}{2150}$ or ± 0.023. Since the factor for number of employees is county totals divided by state totals, the precision of the factor is:

$$P^2 = P_1^2 + P_2^2$$

$$P^2 = (0.0003)^2 + (0.023)^2$$

$$P = \pm 0.023$$

Overall precision - The overall-precision figure for industrial usage of anthracite coal is the product of precisions of the factors just calculated for industrial area source consumption and number of manufacturing employees. The precision is then:

$$P_o^2 = (0.664)^2 + (0.023)^2$$

$$P_o^2 = 0.4414$$

$$P_o = \pm 0.664$$

3.2.6.2 Bituminous Coal - First the total statewide industrial consumption of bituminous coal is determined by consulting the Minerals Yearbook[11] Table 40, pg. 357, under the category "All Others." To determine industrial area source consumption, use the value for statewide industrial point source usage, taking care that coal used for processes (i.e. coke oven charge) is not included. Subtract that value from the total statewide industrial coal combustion to determine the amount of bituminous coal burned by industrial area sources over the state. This figure is then apportioned to counties by assuming that industrial fuel usage in a county is proportional to the total number of manufacturing employees in that county. The number of manufacturing employees for state and county is obtained from the 1967 Census of Manufacturers, "Area Statistics."[15]

In summary, industrial area source combustion of bituminous coal for a county is determined as follows:

$$A_{B.C.} = [I_{B.C.} - P_{B.C.}] \left(\frac{E_c}{E_s}\right)$$

where:

$A_{B.C.}$ = industrial area source combustion of bituminous coal per county

$I_{B.C.}$ = state total combustion of bituminous coal by industrial users

$P_{B.C.}$ = point source combustion of bituminous coal for the state

E_c = number of manufacturing employees in the county

E_s = number of manufacturing employees in the state

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Industrial source consumption of bituminous coal by state[11] - This figure is based on data collected quarterly by the Bureau of Mines from coal handlers who normally sell or produce 100,000 tons or more of coal annually. Reports from these coal handlers are said to cover 94 percent of all coal shipped or produced. The balance is estimated by statistical methods, and the data should be reliable, at least within the limits of the units reported in the table (1,000 tons). For any one state, the maximum error in $I_{B.C.}$ would be ± 500 tons.

Point source combustion of bituminous coal by state - This factor is the summation of the coal usage reported by all industrial point sources. Reports of the amount of coal burned are usually in round figures. Since a source usually has accurate figures for the coal burned, precision depends on the number of significant figures reported, which is usually two or three. In such cases the maximum error would be:

± 5% for two significant figures

± 0.5% for three significant figures

For consistency with the units of $I_{B.C.}$, consider that the point source usage is reported to the nearest 1,000 tons. Assuming random error distribution, the maximum error is ± 500 tons.

Number of manufacturing employees per county and state[15] - The referenced census encompassed all establishments employing one or more persons during the census year

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(1967) and this includes all sources considered as industrial in the scope of the NEDS system. Since an industrial firm can accurately report the number of employees and since all firms were contacted, the census figure should be accurate. But the Census Bureau reports employees to the nearest hundred, leading to a maximum error in E_c of ± 50 employees. If we assume that error is random, the state total will also have a maximum error of ± 50 employees.

Overall precision - To determine the overall precision for area source industrial consumption of bituminous coal assume the maximum error in a factor equals the standard deviation of that factor. For:

$$A_{B.C.} = [I_{B.C.} - P_{B.C.}]\left(\frac{E_c}{E_s}\right)$$

$$\text{Var } A_{B.C.} = A_{B.C.}^{2}\left[\frac{\text{Var}(I_{D.C.} - P_{B.C.})}{(I_{B.C.} - P_{B.C.})^{2}} + \frac{\text{Var } Ec}{E_c^{2}} + \frac{\text{Var } Es}{E_s^{2}}\right]$$

but $\text{Var }(I_{B.C.} - P_{B.C.}) = \text{Var }(I_{B.C.}) + \text{Var }(P_{B.C.})$

therefore:
$$\text{Var } A_{B.C.} = A_{B.C.}^{2}\left[\frac{\text{Var. }(I_{B.C.}) + (\text{Var }(P_{B.C.})}{(I_{B.C.} - P_{B.C.})^{2}} + \frac{\text{Var } E_c}{E_c^{2}} + \frac{\text{Var } E_s}{E_s^{2}}\right]$$

since
$$\frac{\sigma(A)}{A} = \frac{(\text{Var }(A))^{1/2}}{A}$$

$$\frac{\sigma(A_{B.C.})}{A_{B.C.}} = \left[\frac{\text{Var }(I_{B.C.}) + \text{Var }(P_{B.C.})}{(I_{B.C.} - P_{B.C.})^{2}} + \frac{\text{Var } E_c}{E_c^{2}} + \frac{\text{Var } E_s}{E_s^{2}}\right]^{1/2}$$

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Calculating $\frac{\sigma(A_{B.C.})}{A_{B.C.}}$ for several cases according to Appendix C, we obtain the following general equation to define a precision of the area source entry for industrial bituminous coal consumption.

$$\text{precision} = \frac{\sigma(A_{B.C.})}{A_{B.C.}} = 1.26 \times 10^{2} \, (A_{B.C.})^{-0.97}$$

3.2.6.3 Coke - Consumption of coke by area sources can be determined only when local information is available. These data usually come directly from the companies using the coke, who should have reliable figures for annual consumption. Estimating the figures to be precise at least within ± 15 percent, the precision is ± 0.15.

3.2.6.4 Distillate Oil - The industrial area source use of distillate oil statewide is the sum of figures given for "industrial" and "oil companies" in Tables 8 and 9 of Reference 12 (Bureau of Mines) minus the amount consumed by industrial point sources. State totals are then apportioned to counties on the number of manufacturing employees.

The Bureau of Mines totals should be precise within the limits of the nearest thousand barrels for each category. The median values for each category are 662,000 barrels for "industrial" and 74,000 barrels for "oil companies". Assuming that the precision of the median cases applies to all cases gives:

$$T = I + O$$

where T = total consumption of distillate oil by industrial users per state

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I = industrial consumption of distillate oil

O = consumption of distillate oil by oil companies

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{\mathrm{Var}\ (I) + \mathrm{Var}\ (O)}{(I + O)^2}$$

$$\mathrm{Var}\ (I) = (500)^2$$

$$\mathrm{Var}\ (O) = (500)^2$$

$$I + O = 662{,}000 + 74{,}000 = 736{,}000$$

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{5 \times 10^5}{5.41696 \times 10^{11}} = 9.2 \times 10^{-7}$$

$$\frac{\sigma\ (T)}{T} = 9.6 \times 10^{-4}$$

$$\text{precision} = \pm\ 0.00096$$

Consumption of distillate oil by industrial point sources is reported to the nearest thousand gallons. Since most companies keep records of purchases of fuel oil, the figures should be precise within 500 gallons. Assuming that the point source consumption is around 60 percent of the total distillate oil consumption, precision may be determined for the median case.

$$P_p = \frac{500}{0.6(736{,}000)42}$$

$$P_p = \pm\ 2.7 \times 10^{-5}$$

The precision of values derived by apportioning to counties on the basis of manufacturing employees was determined in Section 3.2.6.

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$P_M = 0.023$

The overall precision is determined as follows:

$$A_D = [T_D - P_D] \left(\frac{E_c}{E_s}\right)$$

where A_D = industrial area source consumption of distillate oil

T_D = total consumption of distillate oil by industrial users

P_D = Consumption of distillate oil by point sources

E_c = number of manufacturing employees per county

E_s = number of manufacturing employees per state

$$\frac{\text{Var }(A_D)}{A_D^2} = \frac{\text{Var }(T_D) + \text{Var }P_D}{(T_D - P_D)^2} + \frac{\text{Var }(E_c)}{E_c^2} + \frac{\text{Var }(E_s)}{E_s^2}$$

$$\frac{\text{Var }(E_c)}{E_c^2} + \frac{\text{Var }(E_s)}{E_s^2} = (0.023)^2$$

using median values

$$\text{Var }(T_D) = (\pm\ 5 \times 10^5)42^2 \text{ gallons}^2$$

$$\text{Var }(P_D) = (\pm\ 500 \text{ gallons})^2$$

$$\frac{\text{Var }(A_D)}{A_D^2} = \frac{8.8 \times 10^8 \times 2.5 \times 10^5}{[(736000)42 - 18547200]^2} + (0.023)^2$$

$$\frac{\text{Var }(A_D)}{A_D^2} = \frac{8.8025 \times 10^8}{1.5288827 \times 10^{14}} + 5.29 \times 10^{-4}$$

$$\frac{\text{Var }(A_D)}{A_D^2} = 5.3476 \times 10^{-4}$$

$$\text{precision} = \frac{\sigma\ (A_D)}{A_D} = \pm\ 0.023$$

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3.2.6.5 Residual Oil - The area source use of residual oil statewide is the sum of figures given for "industrial" and "oil companies" in Tables 8 and 9 of Reference 12, minus the amount consumed by industrial point sources. State totals are then apportioned to counties on the basis of the number of manufacturing employees.

Precisions are the same as for distillate oil calculations, but the median values change. On the basis of 950,000 barrels for "industrial" and 178,000 barrels for "oil companies", the precision of the state totals is $\pm 4 \times 10^{-7}$. Precision of the point source totals is $\pm 1.8 \times 10^{-5}$. The overall precision is then:

$$P_o = \left[\frac{\text{Var }(T_R) + \text{Var }(P_R)}{(T_R - P_R)^2} + (0.023)^2 \right]^{1/2}$$

where T_R = total industrial consumption of residual oil

P_R = point source consumption of residual oil

using median values

$$\text{Var }(T_R) = 8.82 \times 10^8$$

$$\text{Var }(P_R) = 2.5 \times 10^5$$

$$(T_R - P_R)^2 = (1.89504 \times 10^7)^2$$

$$(T_R - P_R)^2 = 3.6 \times 10^{14}$$

$$P_o = \left[\frac{8.82 \times 10^8 \times 2.5 \times 10^5}{3.6 \times 10^{14}} + 5.29 \times 10^{-4} \right]^{½}$$

$$P_o = \pm 0.023$$

3.2.6.6 Natural Gas - To determine total area source consumption of natural gas by industrial consumers, the total statewide industrial consumption of natural gas is determined from Table 5, pg. 734 of the Minerals Yearbook under the category "Industrial". Next we consult the point source inventory to obtain industrial point source consumption for the state. The difference between total statewide industrial usage and statewide industrial point source usage is the statewide industrial area source usage of natural gas. This figure is apportioned to counties by assuming that county industrial fuel usage is proportional to the number of manufacturing employees per county. The number of manufacturing employees for state and county is obtained from the 1967 Census of Manufacturers "Area Statistics."

In summary, the determination of industrial usage of natural gas attributable to area sources is as follows:

$$A_{N.G.} = \left[I_{N.G.} - P_{N.G.} \right] \left(\frac{E_c}{E_s} \right)$$

where $A_{N.G.}$ = industrial area source combustion of natural gas per county

$I_{N.G.}$ = total statewide usage of natural gas by industrial firms

$P_{N.G.}$ = statewide point source combustion of natural gas

E_c = number of manufacturing employees in the county

E_s = number of manufacturing employees in the state

Statewide usage of natural gas by industrial firms - These data are based on annual surveys of the companies that

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distribute natural gas; these surveys account for 80 percent of the natural gas produced. Most of the remaining gas usage is covered in the purchase listings of the reporting companies. Assuming that the figure reported covers 95 percent of the natural gas consumed, the precision is ± 0.05.

Statewide point source combustion of natural gas by industrial users - This value is the summation of the natural gas usage reported by all the industrial point sources in the state. It is usually reported in round numbers in units of 10^6 cubic feet. Since the amount of gas used is a readily available, accurate figure, precision will depend on the number of significant figures reported. A value reported to the nearest million cubic feet gives

$$\sigma\ (P_{N.G.}) = \pm\ 0.5 \times 10^6\ \text{ft}^3$$

Number of manufacturing employees per county and per state - The precision for E_c/E_s, determined earlier, is ± 0.023.

D. Overall Precision - For

$$A = (I - P)\left(\frac{E_c}{E_s}\right)$$

$$\text{Var}\ (A) = A^2 \left[\frac{\text{Var}\ (I) + \text{Var}\ (P)}{(I - P)^2} + \frac{\text{Var}\ (E_c)}{(E_c)^2} + \frac{\text{Var}\ (E_s)}{(E_s)^2}\right]$$

but Var (I - P) = Var (I) + Var (P)

$$\text{Var}\ (A) = A^2 \left[\frac{\text{Var}\ (I) + \text{Var}\ (P)}{(I - P)^2} + \frac{\text{Var}\ (E_c)}{(E_c)^2} + \frac{\text{Var}\ (E_s)}{(E_s)^2}\right]$$

$$\left[\frac{\text{Var}\ (E_c)}{(E_c)^2} + \frac{\text{Var}\ (E_s)}{(E_s)^2}\right] = (0.023)^2$$

Assume that the precision for the median value of $I_{N.G.}$ applies to all cases. The median value of $I_{N.G.}$ from the Minerals Yearbook is 86,682 x 10^6 cubic feet.

$$\sigma\ (I_{N.G.}) = .05\ I_{N.G.}$$

$$\mathrm{Var}\ (I_{N.G.}) = (.05\ I_{N.G.})^2$$

$$\mathrm{Var}\ (I_{N.G.})_{\mathrm{median}} = 1.878 \times 10^{19}$$

Assume that point sources account for 60 percent of the natural gas consumed by industrial users.

$$P_{N.G.\ \mathrm{median}} = 0.6\ (86682 \times 10^6)$$

$$(P_{N.G.}) = 0.5 \times 10^6$$

$$\mathrm{Var}\ (P_{N.G.}) = 2.5 \times 10^{11}$$

$$\frac{\mathrm{Var}\ (A_{N.G.})}{(A_{N.G.})^2} = \frac{1.878 \times 10^{19} + 2.5 \times 10^{11}}{(3.46728 \times 10^{10})^2} + (0.023)^2$$

$$\frac{\mathrm{Var}\ (A_{N.G.})}{A_{N.G.}} = 1.56 \times 10^{-2} + 5.29 \times 10^{-4}$$

$$\mathrm{precision} = \frac{\sigma\ (A_{N.G.})}{A_{N.G.}} = \pm\ 0.127$$

3.2.6.7 Wood - Usage of wood by industrial sources not classified as point sources must be estimated from data supplied by these sources. Although a company may provide a good estimation of the feed rate to their boiler, error may be introduced if the density of the wood is not constant. Accounting for this type of error, assume that the estimation is precise within 25 percent and precision is ± 0.25.

3.2.6.8 Process Gas - Use of process gas by industrial area sources can be determined only from local information. The most common users of process gas are petroleum refining operations and natural gas production plants. They usually cannot provide a measurement in cubic feet but can supply their heater or boiler capacity. Because of the varying heat content of process gas, the volume of gas required to fire the heater or boiler to capacity also varies. At best the number provided by the user is an estimate, which should be precise within 20 percent.

$$P = \pm 0.20$$

3.2.7 On-Site Incineration

On-site incineration refers to disposal in small incinerators, such as backyard burners, industrial incinerators, and incinerators at food and department stores, hospitals, and schools. Per-capita generation rates are derived from the 1968 National Survey of Community Solid Waste Practices[16,17] which provides a good indication of the methods of solid waste disposal but a poor indication of the quantities involved. Analysis of the data gives a precision for each category in the range of ± 10.00. Assume that this precision applies to all categories of users, i.e., industrial, residential, and commercial-institutional.

3.2.8 Open Burning

On-site burning refers to the unconfined burning of waste such as leaves, landscape refuse, or other rubbish.

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Factors for per-capita generation rate were also derived from the 1968 National Survey of Community Solid Waste Practices[16,17]. Again, determination of the quantity of waste based on this survey is very imprecise. Based on the data examined for on-site incineration, a precision of ± 10.00 is estimated for residential, commercial-institutional, and industrial sources of open burning.

3.2.9 Measured Vehicle Miles

Entries are made in these fields of the NEDS form only if a transportation study is available giving the measured vehicle miles traveled. The vehicle miles are categorized by roadway types based on average speeds. Since the data for all roadway types are from the same source, the data for each type should have the same precision. The Bureau of Census reports that data gathered in the Census of Transportation has a standard deviation of 3.2 percent.

Assume that all transportation studies are as precise as the Census of Transportation. On the basis of Bureau of Census data, precisions of values for measured vehicle miles on all types of roadways (limited access, rural, suburban, urban) is ± 3.2 percent.

3.2.10 Gasoline Fuel

Three methods are used in calculating consumption of gasoline by on-highway vehicles. Since two of the three methods are interrelated, consider only two methods for calculation of precisions. Method 1 is applied only when there is available a transportation study that provides measured vehicle miles. The study should classify mileage by light- and heavy-duty gasoline vehicles and by heavy-duty diesel vehicles. Method 2 involves obtaining the total statewide gasoline sales from Highway Statistics[18] and apportioning values to counties on the basis of population.

Off-highway gasoline usage is calculated by applying a factor for annual consumption by farm tractors along with a population-based factor to include other off-highway sources.

3.2.10.1 Light-Duty Vehicle - In Method 1 the value for total light-duty vehicle miles is divided by 13.6 miles per gallon[19] to obtain total volume of gasoline consumed by light-duty vehicles. Both factors are obtained from transportation studies and each should have a precision of ± 0.032 (see Section 3.2.9). The overall precision is then:

$$P_o^2 = P_1^2 + P_2^2$$

$$P_o^2 = (0.032)^2 + (0.032)^2$$

$$P_o^2 = 0.002048$$

$$P_o = \pm 0.0453$$

Method 2 involves obtaining the statewide sales of gasoline for highway use, apportioning the gasoline to counties on the basis of the ratio of county service station sales to state service station sales, calculating total gasoline vehicle miles traveled (VMT) by assuming an average 12.2 miles per gallon, assuming that light-duty vehicles

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account for 89 percent of the total VMT, and assuming that light-duty vehicles obtain 13.6 miles per gallon to obtain gallons consumed by light-duty vehicles. The precision of each factor employed must be calculated to obtain the overall precision.

Published gasoline sales totals by state - This figure is obtained from Highway Statistics.[18] It is compiled from reports by state tax departments and should be a precise figure since tax records are precise.

County service station sales and state service station sales - These figures are obtained from the 1968 Census of Business.[20] The Bureau of Census reports that 80 percent of all stations were canvassed by mail and data for the remaining were obtained by consulting records of the IRS and Social Security Administration. Assuming that the records are accurate, there should be no imprecision other than that introduced by rounding off to the nearest $1,000. Considering the magnitude of sales at service stations, an error of ± $1,000 is insignificant. Therefore consider the sales totals as precise numbers.

12.2 miles per gallon average for all vehicles - This figure, obtained from Highway Statistics,[18] represents the total vehicle miles in the nation divided by the total gasoline consumed. The total VMT is precise within ± 3.2 percent, and the value for gasoline consumed is a precise number. Therefore, the result is also precise within ± 0.032.

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89 percent of total vehicle miles are contributed by light-duty vehicles - This figure is obtained from Highway Statistics[18] by finding the ratio of light-duty vehicle miles to heavy-duty vehicle miles. Since each value has a precision of 3.2 percent, the overall precision is determined as follows:

$$P_o^2 = P_1^2 + P_2^2$$

$$P_o = \sqrt{P_1^2 + P_2^2}$$

$$P_o = \sqrt{2(.032)^2}$$

$$P_o = \pm 0.045$$

13.6 miles per gallon average for light-duty vehicles - This value, also from Highway Statistics,[18] is obtained by dividing the total light-duty VMT by the gasoline consumed by light-duty vehicles. Since the same precisions are involved as before, the precision of this value is also ± 0.032.

Overall precision - Multiplying precisions of the five factors just calculated gives the overall precision of the value for off-highway gasoline consumption as obtained by Method 2:

$$P_o = [(0)^2 + (0.032)^2 + (0.032)^2 + (0.045)^2 + (0.032)^2]^{1/2}$$

$$P_o = [0.005097]^{1/2}$$

$$P_o = \pm 0.071$$

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3.2.10.2 Heavy Vehicle - The methods for determining gasoline consumption by heavy vehicles are exactly the same as those for light vehicles. The values of the factors change slightly, but the sources are the same and the precisions are the same. For Method 1, with values obtained from a transportation study, the precision is ± 0.045; for Method 2, which involves apportioning, the precision is ± 0.071

3.2.10.3 Off-Highway - The total off-highway consumption of gasgasoline is the sum of that used by farm tractors and the amount consumed by other miscellaneous off-highway sources.

Gasoline usage by farm tractors - The total gasoline used by farm tractors is obtained by finding the total number of farm tractors in a county in the Census of Agriculture,[23] assuming that 60 percent are gasoline powered, and applying a factor of 1,000 gallons per tractor per year. Assuming that all these factors are derived from Department of Agriculture figures, and that only counties with 100 or more farms are significant, Table C of the Census of Agriculture[23] may be used to estimate precisions. Using the Table's levels of reliability for fuels and machinery, the precisions for both the fuel consumption factor and the percentage of tractors powered by gasoline are ± 0.10 and the precision of the number of tractors is ± 0.042. The overall precision is then:

$$P_o = \sqrt{P_1^2 + P_2^2 + P_3^2}$$

$$P_o = \sqrt{2(.10)^2 + (.042)^2}$$

$$P_o = \pm 0.148$$

Miscellaneous off-highway gasoline consumption - This figure is obtained by using a consumption factor of 13 gallons per capita-year and multiplying by the county population. APTD-1137[7] gives no reference for the factor of 13 gallons per capita-year; therefore we assume that the factor is significant only to the nearest ten. This would give a standard error of ± 5 or a precision of ± 0.385. Since the county population is a precise figure, the precision is ± 0.385.

Overall precision - The total off-highway gasoline consumption is the sum of farm tractor usage and miscellaneous usage. Therefore the overall precision is as follows:

$$T = F + M$$

where T = total off-highway gasoline consumption

F = gasoline consumed by farm tractors

M = gasoline consumed by miscellaneous off-highway sources

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{\mathrm{Var}\ (F + M)}{(F + M)^2}$$

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{\mathrm{Var}\ F + \mathrm{Var}\ M}{(F + M)^2}$$

$$\sigma(F) = 0.148\ F$$

$$\sigma(M) = 0.385\ M$$

$$\mathrm{Var}\ (F) = 0.022\ F^2$$

$$\mathrm{Var}\ (M) = 0.148\ M^2$$

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{0.022\ F^2 + 0.148\ M^2}{F^2 + 2\ FM + M^2}$$

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but $M = 13 \times \text{population } (P)$

and $F = T - M$

therefore $$\frac{\text{Var }(T)}{T^2} = \frac{0.022\ (T - 13P)^2 + 0.148\ (13P)^2}{(T - 13P)^2 + 2\ (13P)(T - 13P) + (13P)^2}$$

$$\frac{\text{Var }(T)}{T^2} = \frac{0.022T^2 - 0.572\ TP + 28.730P^2}{T^2}$$

$$\frac{\sigma(T)}{T} = \left[\frac{\text{Var }(T)}{T^2}\right]^{1/2}$$

$$\text{precision} = \frac{\sigma\ (T)}{T} = \frac{[0.022T^2 = 0.572TP + 28.73P^2]^{1/2}}{T}$$

3.2.11 Diesel Fuel

This category includes on-highway heavy vehicle use, off-highway use by miscellaneous sources, and rail locomotive use. The various methods used for calculating each case are explained in the following sections.

3.2.11.1 Heavy Vehicle - Methods of calculation are the same as those for calculating gasoline consumption. The first method involves dividing the measured vehicle miles traveled by diesel-powered vehicles by a factor of 5.1 miles per gallon. Both figures are obtained from transportation studies and should have the precision indicated earlier, 0.032. The overall precision is then:

$$P_o^{\,2} = P_1^{\,2} + P_2^{\,2}$$

$$P_o^{\,2} = (0.032)^2 + (0.032)^2$$

$$P_o = \pm\ 0.045$$

The second method involves apportionment of statewide diesel fuel sales to counties on the basis of service station sales.

Statewide diesel fuel sales - This figure is given as "on-highway use of special fuels" in Highway Statistics.[18] It is obtained from data reported by state tax agencies and should be a precise figure.

County service station sales and state service station sales - These figures for sales of diesel fuel are from 1968 Census of Business and are precise numbers.

Overall precision - The factors used in calculating diesel fuel use are precise, but the coding form requires rounding off to the nearest thousand gallons. The precision is then:

$$P = \frac{\pm\ 0.5}{\text{No. in field}}$$

3.2.11.2 Off-highway - Off-highway diesel fuel consumption is the sum of that used by farm tractors, construction equipment, and other miscellaneous sources.

Diesel fuel usage by farm tractors - The method described for calculation of gasoline usage by tractors applies to calculating diesel fuel usage except that 35 percent of the tractors are assumed to be diesel-powered. The same precisions apply.

$$P = \pm\ 0.148$$

Diesel fuel usage by construction equipment - The value for diesel fuel usage by construction equipment is the

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product of the number of non-building construction employees in the county and a factor of 5,000 gallons per employee-year. The number of non-building construction employees, reported in County Business Patterns[24] is obtained by consulting data from the Social Security Administration and, if needed, by a special multiunit survey. It should be a precise number. The fuel consumption figure should be precise within the limits of significant figures. Precision is then $\frac{+500}{5000}$ or ± 0.10.

Diesel fuel usage by miscellaneous sources - This figure is calculated by applying a factor of 7.4 gallons per capita annually. Since no source is listed for the factor, assume that it is significant only to the nearest unit. Since population is a precise figure, the precision equals $\frac{0.5}{7.4}$ or ± 0.07.

Overall precision - It is difficult to determine a precision for all cases without deriving an equation in terms of factors that do not appear on the NEDS area source coding form. Therefore, assume that the precision applying to a median case applies to all cases. The median value for diesel fuel consumed by farm tractors is 792,050 gallons. The median value for diesel fuel consumed by construction equipment is 970,000 gallons, based on 194 non-building construction workers per county. The median value for diesel fuel consumption by other miscellaneous sources is 105,235 gallons gased on a county population of 14,221.

precision median =

$$\left[\frac{(0.148 \times 792{,}050)^2 + (0.1 \times 970{,}000)^2 + (0.07 \times 105{,}235)^2}{(79{,}250 + 970{,}000 + 105{,}235)^2}\right]^{1/2}$$

$$= \pm\ 0.082$$

3.2.11.3 Rail Locomotive - Sales of fuel oil to railroads by state are given in Reference 12, Table 10. County fuel totals are obtained by apportionment on the basis of miles of track per county.

The Bureau of Mines totals may be considered precise within the reported units of 1,000 barrels. Assuming that the median value of 1,231,000 barrels applies to all cases gives a precision of $\frac{500}{1{,}231{,}000}$ or $\pm\ 0.4 \times 10^{-3}$.

Values for miles of track per county are obtained from detailed state maps or may be supplied by the railroads. Assuming that the figure obtained is precise with 10 percent gives an overall precision as follows:

$$P_o^2 = (0.10)^2 + (0.4 \times 10^{-3})^2$$

$$P_o^2 = 0.010 + 1.6 \times 10^{-7}$$

$$P_o = \pm\ 0.10$$

3.2.12 Aircraft

This category includes all aircraft operations except operations on dirt airstrips. The required values for landing and takeoff (LTO) cycles are obtained from three Federal Aviation Administration publications,[25-27] which report the number of "operations" performed by civil, commercial, and military aircraft at all FAA-regulated airports and military airfields. The number of "operations" is divided by 2 to obtain the number of LTO cycles.

3.2.12.1 Military Aircraft - The exact number of operations performed by military aircraft is reported in Military Air Traffic Activity Report[26] and F.A.A. Air Traffic Activity[25]. Therefore, the LTO cycles may be determined precisely. The units of the NEDS form field limit precision, in that the figure must be reported to the nearest 100. Precision is then equal to $\frac{\pm 50}{\text{no. LTO cycles}}$.

3.2.12.2 Civil Aircraft - Civil aircraft operations are also enumerated in F.A.A. Air Traffic Activity[25] and Military Air Traffic Activity Report.[26] Since these reports do not include operations at non-FAA-regulated airfields, figures for these operations must be obtained from the appropriate airfield officials, who should provide an exact figure. Therefore, precision of the number of LTO cycles is limited only by rounding to the nearest 10 as required on the NEDS coding form. The precision will be $\frac{\pm 5}{\text{no. of LTO cycles}}$.

3.2.12.3 Commercial aircraft - The number of LTO cycles for commercial aircraft is detemrined in exactly the same manner as that for civil aircraft and has the same precision, which is

$$\frac{\pm 5}{\text{No. of LTO cycles}}.$$

3.2.13 Vessels

This category, which includes vessels and small craft, is sub-categorized according to type of fuel.

3.2.13.1 Anthracite Coal - No reliable method for estimating emissions from these vessels on a local basis is currently known, because only nationwide fuel totals are available.[11]

Thus information on local fuel consumption can be obtained only from estimates made by port authorities or ship operators.

Anthracite coal usage should be assigned to counties with major ports, according to tonnage handled in the ports. These data are available from Waterborne Commerce of the United States,[28] published by the U.S. Army Corps of Engineers.

The nationwide totals are reported to the nearest thousand tons. The number should be precise wihtin this limitation; for 1969 the precision is $\frac{500}{17,000}$ or 0.03.

Waterborne Commerce of the United States reports the tonnage handled in the ports to the nearest ton. Since all ships are required by law to report their tonnage, this should be a precise figure. The overall precision of the value for anthracite coal consumption by vessels is then ± 0.03.

3.2.13.2 Diesel Oil - Detailed apportioning methods for determining fuel oil consumption by vessels are given in APTD-1135.[7] Assume that all data from Waterborne Commerce of the United States are precise.

In-port fuel consumption - The number of vessels entering a port, obtained from Reference 28, is a precise number. Assume that each vessel spends 3 days in port, and estimate that this figure is precise within 1/2 day or $\frac{0.5}{3}$ = 0.167. The vessel-days in port must be distributed between ships using distillate (diesel) fuel and ships using residual fuel. This is accomplished by using the ratio of distillate oil vessel-days to residual oil vessel-days. First, obtain the number of barrels of each fuel consumed in

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the state from Reference 12. Convert to vessel-days by assuming that each vessel consumes 660 gal/day of diesel fuel and 1900 gal/day of residual oil. Assuming that these figures are precise within their significant figures gives precision of the diesel fuel factor equal to $\frac{5}{660}$ or ± 0.008 and precision of the residual fuel factor equal to $\frac{50}{1900}$ or ± 0.026. Using median values for total statewide fuel oil consumption by vessels, with a standard deviation of ± 21,000 gallons gives the following precision:

distillate oil - 8,484,000 gallons

residual oil - 7,854,000 gallons

$$\text{distillate-oil vessel-days} = \frac{8,484,000}{660} = 12,855$$

$$\text{precision} = \left[\left(\frac{21,000}{8,484,000}\right)^2 + (0.008)^2\right]^{1/2}$$

$$= \pm\ 0.009$$

$$\text{residual-oil vessel-days} = \frac{7,854,000}{1,900} = 4,134$$

$$\text{precision} = \left[\left(\frac{21,000}{7,854,000}\right)^2 + (0.026)^2\right]^{1/2}$$

$$= \pm\ 0.061$$

$$\text{total vessel-days} = 12,855 + 4,134$$

$$= 16,989$$

$$\text{precision} = \left[\frac{(0.009 \times 12,855)^2 + (0.061 \times 4,134)^2}{(16,989)^2}\right]^{1/2}$$

$$= \pm\ 0.02$$

$$\text{percent diesel-oil days} = \frac{12,855}{16,989}$$

$$\text{precision} = [(0.009)^2 + (0.02)^2]^{1/2}$$

$$= \pm\ 0.022$$

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total diesel-oil days = percent diesel days x number of vessels x 3 days/vessel

$$\text{precision} = [(0.022)^2 + 0^2 + (0.167)^2]^{1/2}$$

$$= \pm 0.009$$

$$\text{residual-oil vessel-days} = \frac{7,854,000}{1,900} = 4,134$$

$$\text{precision} = [(\frac{21,000}{7,854,000})^2 + (0.026)^2]^{1/2}$$

$$= \pm 0.061$$

$$\text{total vessel-days} = 12,855 + 4,134$$

$$= 16,989$$

$$\text{precision} = [\frac{(0.009 \times 12,855)^2 + (0.061 \times 4,134)^2}{(16,989)^2}]^{1/2}$$

$$= \pm 0.02$$

$$\text{percent diesel-oil days} = \frac{12,855}{16,989}$$

$$\text{precision} = [(0.009)^2 + (0.02)^2]^{1/2}$$

$$= \pm 0.022$$

total diesel-oil days = percent diesel-oil days x number of vessels x 3 days/vessel

$$\text{precision} = [(0.022)^2 + 0^2 + (0.167)^2]^{1/2}$$

$$= \pm 0.17$$

diesel-oil consumption = total diesel-oil days x 660 gallons per day

$$\text{precision} = [(0.17)^2 + (0.008)^2]^{1/2}$$

$$= \pm 0.17$$

Underway fuel consumption - Underway diesel fuel consumption is assumed to be the difference between the total distillate oil used by vessels (Reference 12), and the total distillate fuel consumed in-port. Using median values, the

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in-port consumption of distillate is 4,437,668 gallons out of a total of 8,484,000 gallons. Precision of underway diesel fuel consumption is then:

$$\text{precision } \left[\frac{(0.17\times 4,437,668)^2 + (21,000)^2}{(8,484,000 - 4,437,668)^2}\right]^{1/2}$$

$$\text{precision} = \pm\ 0.187$$

Overall precision - Precision of the value for total diesel fuel usage by vessels equals precisions of the in-port consumption value plus precision of the underway consumption value. Based on median values:

$$\text{precision} = \left[\frac{(0.17 \times 4,437,668)^2 + (0.187 \times 4,046,332)^2}{8,484,000^2}\right]^{1/2}$$

$$\text{precision} - \pm\ 0.13$$

3.2.13.3 Residual oil - In-port residual oil consumption is calculated in the same manner as for diesel fuel. From the preceding section, precision of residual-oil vessel-days equals ± 0.061, precision of total vessel-days equals ± 0.02, and precision of the residual fuel factor equals ± 0.026.

$$\text{precision} = [(0.061)^2 + (0.02)^2]^{1/2}$$

$$= \pm\ 0.064$$

total residual-oil days = percent residual-oil days x number of vessels x 3 days/vessel

$$\text{precision} = [(0.064)^2 + 0^2 + (0.167)^2]^{1/2}$$

$$= \pm\ 0.018$$

residual oil consumption = total residual-oil days x 1900 gallons/day

$$\text{precision} = [(0.18)^2 + (0.026)^2]^{1/2}$$

$$= \pm\ 0.18$$

3.2.13.4 Gasoline - This category includes craft operated by inboard, outboard, or inboard-outboard motors on lakes and rivers. Gasoline consumption by vessels can be estimated by using a factor of 160 gallons of gasoline per boat registration per year. This factor was derived from information on average annual operating hours, average horsepower per vessel, and average fuel consumption per horsepower-hour of operation. The estimate also approximately accounts for any non-motorized boats that may be included in the state total of registrations and for boats with small outboard motors that may not be registered. Boat registration data should be obtained from the appropriate state agency, such as the State Department of Recreation of the Fish and Game Department.

The total gasoline consumption predicted by use of the state total of boat registrations should be apportioned to counties on the basis of inland water surface area. County inland water areas may be determined from the Bureau of the Census' Area Measurement Reports.[29]

The factor of 160 gallons per boat registration should be a good estimate of gasoline consumption. Assuming that it is precise within 25 gallons for each county, the precision is $\frac{25}{160}$ or $\pm$ 0.156.

The number of boat registrations is a precise number.

The surface area of water in a state is reported in square miles. The Bureau of Census reports that the figures are accurate

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within 1 percent. Based on median values for county and state, precision for the state figure is 0.01, but the county figure is less precise because of rounding off: P equals $\frac{0.5}{21.9}$ or 0.023.

Based on median values, the overall precision of a value for gasoline consumption by vessels is:

$$P_o = [(0.156)^2 + (0.01)^2 + (0.023)^2]^{1/2}$$

$$P_o = \pm 0.158$$

3.2.14 Evaporation

This category includes losses of hydrocarbons and other organic compounds by evaporation at sources not considered as point sources. These sources include gasoline-handling, dry cleaning, surface coating, and miscellaneous solvent-use operations.

3.2.14.1 Solvent-Purchased Methods of Determination - Methods for determining evaporation losses as a function of solvent purchases entail (1) a questionnaire survey of all solvent users, or (2) the assumption that solvent use is proportional to population and is dependent on the population density.

Questionaire survey of all solvent users - A survey is the best and most accurate method of determining solvent use. Most companies maintain records of purchase orders that show solvent use. Precision depends on the significant figures reported on the questionnaires. Although this figure varies among the reporting companies, one can assume that it is reported within ± 50 tons. Precision is then:

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$$P = \pm \frac{50}{\text{No. in field}}$$

Assume solvent use is proportional to population and dependent on population density - This method is used for most counties, since surveys require considerable time and effort.

For dry cleaning operations use factors of 2 lb solvent per person per year in moderate climates and 2.7 lb per person per year for colder climates.

For other solvent losses apply values from the following table:

County Population	Solvent Loss, lb per capita per year
<100,000	3
100,000 to 500,000	8
500,000 to 1,000,000	18
>1,000,000	28

Since APTD-1135 does not cite references from which these factors for evaporation losses were obtained, the best possible precision value is based on an engineering estimate.

Losses from dry cleaning operations are based on population, climate, and factors for dry cleaning loss per person. Since the population value is a precise figure, all imprecision arises from the factors dependent on climate; that is, 2 and 2.7 lb/person for moderate and cold climates, respectively. Assuming

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that the factors are correct, the usage should cover a range from 2 to 2.7, since climate does not change abruptly from moderate to cold. If errors are randomly distributed, the range 2.0 to 2.7 should contain 99 percent of the values. Assuming the range is 3 standard deviations, T = ± 0.2333. Related to a median value of 2.35 for the use factor, the precision equals ± 10 percent.

Other solvent losses are also considered in this category. Since the population figure is precise, any imprecision results from errors in the solvent-use factors. Estimating the error in each factor as ± 5 and using the median value for each range, precision for each range is determined:

T = total solvent loss

D = dry cleaning loss

S = miscellaneous solvent loss

X = population

$\sigma(D) = 0.1\ (2.35)(X)$

$\sigma(S) = 5\ (X)$

$\text{Var}\ (D) = [\sigma\ (D)]^2 = 0.055225\ X^2$

$\text{Var}\ (S) = [\sigma\ (S)]^2 = 25\ X^2$

Since T = D + S

$$\frac{\text{Var}(T)}{T^2} = \frac{\text{Var}(D) + \text{Var}(S)}{(D + S)^2}$$

$\text{Var}(T) = 25.055225\ X^2$

$\sigma(T) = \sqrt{25.055225\ X^2}$

$\sigma(T) = 5.00552\ X$

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Range	T	$P = \frac{\sigma(T)}{T}$
0 - 100,000 (X = 50,000)	5.35 X	± 0.936
100,000-500,000 (X = 300,000)	10.35 X	± 0.484
500,000-1,000,000 (X = 750,000)	20.35 X	± 0.246
>1,000,000 (X = 1,500,000)	30.35 X	± 0.165

3.2.14.2 Gasoline Handling - This category includes only evaporative losses that occur as a result of service station operations. Among three possible data collection methods, the most common method involves totaling the entries for light vehicle, heavy vehicle, and off-highway consumption of gasoline. Precision then depends on the precisions of these entries. For most counties, off-highway consumption is negligible in comparison with consumption by light and heavy vehicles. Assume then that precision depends only on the precisions of values for light and heavy vehicle consumption:

$$T = L + H$$

where T = gasoline marketed at service stations

L = light-vehicle gasoline usage

H = heavy-vehicle gasoline usage

$$\frac{\text{Var }(T)}{T^2} = \frac{\text{Var }(L) + \text{Var }(H)}{(L + H)^2}$$

but $T^2 = (L + H)^2$

therefore

$$\frac{\text{Var }(T)}{T^2} = \frac{\text{Var }(L) + \text{Var }(H)}{T^2}$$

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$$\mathrm{Var}\ (L) = [\sigma(L)]^2 = (0.071L)^2 \text{ (per Section 3.2.10.1)}$$

$$\mathrm{Var}\ (H) = [\sigma(H)]^2 = (0.072H)^2 \text{ (per Section 3.2.10.2)}$$

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{0.0050L^2 + 0.0052H^2}{T^2}$$

Assume that light vehicles using 13.6 miles per gallon account for 89 percent of the VMT and heavy vehicles using 8.4 miles per gallon account for 11 percent; then

$$H = .2L$$

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{0.0050L^2 + 0.0052(0.2L)^2}{T^2}$$

$$\frac{\mathrm{Var}\ (T)}{T^2} = \frac{0.00521L^2}{T^2}$$

$$\frac{\sigma\ (T)}{T} = \frac{0.072L}{T}$$

but $T = 1.2L$

$$\frac{\sigma\ (T)}{T} = 0.060$$

precision = ± 0.060

3.2.15 Fugitive Dust Sources

This section deals with precision of values reported for emissions of fugitive dust from sources that include dirt roads, dirt airstrips, construction sites, rock handling sites, and several miscellaneous sources.

3.2.15.1 Dirt Roads - The value for vehicle miles of travel on dirt roads is obtained by using the figure given by the State

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Highway Department for total mileage of dirt roads in each county and by estimating the amount of traffic.

The State Highway Department usually can supply a figure for the mileage of dirt roads that is precise within the nearest mile. Estimating at least 10 miles of dirt road per county as a median value gives a precision of $\frac{0.5}{10}$ or ± 0.05.

Estimating the number of vehicles that travel over dirt roads introduces more imprecision. If at least some data are available on which to base an estimate, the figure for number of vehicles should be precise within 50 percent.

The overall precision is then:

$$P_o^2 = (0.5)^2 + (0.05)^2$$

$$P_o = \pm 0.502$$

3.2.15.2 Dirt Airstrips - Airstrip operators who are contacted for the required information should be able to supply the exact number of LTO cycles performed on the airstrip.

Precision = ± 0

3.2.15.3 Construction Sites - This category includes construction sites and other areas subject to severe soil erosion. These areas are estimated by the appropriate state officials, presumably to the nearest 5000 acres with precision.

$$\text{precision} = \frac{\pm 5000}{\text{No. in field}}$$

3.2.15.4 Rock Handling and Storage - These are sources too small to qualify as point sources. For rock-handling operations, state offices should have registration forms giving thruput

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values. Each source should report thruput precisely at least to the nearest thousand tons. The precision of the area source totals then depends on the units reported. The figure is rounded to the nearest thousand tons, giving precision equal to:

$$P = \frac{\pm 0.5}{\text{No. in field}}$$

3.2.16 Miscellaneous Sources

Sources in this category are characterized by intermittent emissions of fugitive dust. Techniques for collection of data for estimating emissions generally do not yield precise values.

3.2.16.1 Forest Fires -

Area - Data on areas involved in forest fires are obtained from the U.S. Forest Service or from state forest agencies, which report acreage to the nearest acre. It is doubtful that these acres are measured precisely, without the use of aerial photography, which yields the most precise value for affected acreage but is not used by most state forest agencies. Other methods of measurement involve estimation of the extent of the fire by personnel using maps or other indicators to determine dimensions of the burned area. These estimates will produce a precise figure if the outer limits of the burned area are determined carefully. Assuming this is the case, the area value should be precise within ± 0.05.

Quantity (tons/acre) - A value for tons of wood per acre is also obtained from the U.S. or state forestry services. If data are not available, use 40 tons/acre for heavily forested

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areas or 20 tons/acre for thinly forested areas. Since no data are at hand on which to base a precision value, assume that the density of forestation is precise within ± 0.15.

3.2.16.2 Slash Burning -

Area - This category includes areas of slash burning and of agricultural field burning. Values for slash burning areas can be obtained from the U.S. Forest Service or the state Forestry Department.

Values for agricultural field burning area must be estimated by the state Agricultural Department. Precision values vary from county to county dependent on: 1) whether burning is extensive in the locale; 2) significant figures reported; 3) sources of the data. The best precision estimate must be based on several assumptions to be applied to all counties.

Where the total slash burning area in the county is less than 100 acres, assume the number is precise within ± 50 percent. Where the total burning area is 100 acres or greater, assume the figure is precise within 50 acres.

$$\text{precision} = \frac{\pm 50}{\text{No. in field}}$$

Quantity (tons/acre) - The quantity of timber that is slash-burned should be obtainable from the U.S. Forest Service or the state Forestry Department. If it is not, use 75 tons/acre.

For agricultural field burning area use a state Agricultural Department estimate or a factor of 2.5 tons/acre.

For counties in which both slash and agricultural field

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burning are practiced, use a weighted average.

Again, a precision value applicable to all counties is determined on the basis of these assumptions:

1. Assume that all counties with a figure in this field have both slash and agricultural field burning.
2. Assume the same precision for values obtained for slash and agricultural field burning: ± 0.25.

3.2.16.3 Frost Control

Number of orchard heaters - County or state Agricultural Departments probably can indicate the number of orchard heaters in use. Local orchard operators can confirm this information or give a better figure. Assuming that orchard operators are willing to supply this information, the figure should be precise within the nearest hundred as reported on the NEDS area source coding form.

$$\text{precision} = \frac{\pm 50}{\text{No. of orchard heaters}}$$

Firing days per year - Determine this figure by a representative sampling of orchard grove operators. Assume that all heaters in a county are fired for the same amount of time and that the number reported is precise at least within 10 days:

$$\text{precision} = \frac{\pm 5.0}{\text{days per year}}$$

3.2.16.4 Structure fires - Local fire control agencies can supply the number of structural fires. Assume that the number of unrecorded or unreported fires is 5 or less: precision is

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then equal to $\frac{\pm 5.0}{\text{No. of fires}}$.

3.2.16.5 Coal refuse burning - Coal refuse piles consist of below-standard coal that has been discarded. Ignition of these piles and smoldering cause significant air pollution.

Size of bank - Three dimensions of the bank are estimated to obtain the volume. The area factor should be precise with 10 percent, since maps can usually give detailed outlines of the bank. Estimation of depth of the bank introduces more error, since depths vary according to the terrain on which burning occurs. Estimate that the depth factor is precise within 25 percent. Precision is then calculated as follows:

$$P^2 = (0.10)^2 + (0.25)^2$$

$$P = \pm 0.27$$

Number of burning coal refuse piles - The state air pollution control agency should provide an exact number of coal refuse burning operations:

$$\text{precision} = \pm 0$$

3.3 PRECISION OF AUTOMOTIVE EMISSION FACTORS

As with emissions from point sources and from other area sources, we consider emissions from automotive vehicles in terms of priority and non-priority pollutants. We did not make a detailed study and determination of precision of emission factors for non-priority pollutants from motor vehicles. Instead, we apply to this category the average precisions calculated for emission factors for non-priority pollutants from point sources.

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These precision values were calculated in Section 2.1.3 and are summarized below:

	Part.	SO_x	HC	CO
Average precision	0.211	0.146	0.237	0.357

Precisions of all automotive emission factors are summarized in Table 3.4.

Table 3.4. PRECISIONS OF MOTOR VEHICLE EMISSION FACTORS

Road Type	Vehicle classification	Precision				
		Part.	SO_x	NO_x	HC	CO
Urban	LDG	0.211	0.146	0.028	0.025	0.036
	HDG	0.211	0.146	0.028	0.019	0.034
	HDD	0.211	0.146	0.035	0.237	0.357
Suburban	LDG	0.211	0.146	0.028	0.024	0.036
	HDG	0.211	0.146	0.028	0.019	0.034
	HDD	0.211	0.146	0.035	0.237	0.357
Rural	LDG	0.211	0.146	0.028	0.024	0.036
	HDG	0.211	0.146	0.028	0.018	0.035
	HDD	0.211	0.146	0.035	0.237	0.357
Limited Access	LDG	0.211	0.146	0.028	0.023	0.036
	HDG	0.211	0.146	0.028	0.018	0.035
	HDD	0.211	0.146	0.035	0.237	0.357

The balance of this section is devoted to calculations of precisions of the priority pollutant emission factors as they are related to several categories of motor vehicles. The priority pollutants for light-duty and heavy-duty gasoline-powered highway vehicles are NO_x, HC, and CO. For heavy-duty, diesel-powered highway vehicles the priority pollutant is NO_x.

Because it is not possible to determine the exact process by which the emission factors were calculated for use in the NEDS program, several assumptions are necessary. Using the data and procedure outlined in AP-42, we assume that the 1-year-old vehicles in the population are of the 1973 model year and apply the emission rates and deterioration factors designated for low-altitude areas (excluding California).

3.3.1 Light-Duty, Gasoline-Powered Highway Vehicles

Emission factors for light-duty, gasoline-powered highway vehicles (LDG) are calculated by the method presented in Section 3.1.2 of AP-42, in which LDG exhaust emission factors for NO_x, HC, and CO are expressed mathematically as:

$$e_{np} = \sum_{i=n-12}^{n+1} c_i d_i m_i s_i$$

where

e_{np} = Emission factor in grams per vehicle mile for calendar year (n), and pollutant (p)

c_i = The 1975 Federal test procedure emission rate for pollutant (p) in g/mi for the i^{th} model year at low mileage

d_i = The controlled vehicle pollutant (p) emission deterioration factor for the i^{th} model year at calendar year (n)

m_i = The weighted annual travel of the i^{th} model year during calendar year (n). The determination of this variable involves the use of the vehicle model year distribution

s_i = The weighted speed adjustment factor for the i^{th} model year vehicles

The factor for evaporative and crankcase emissions of HC is calculated and added to the exhaust HC emission factor to give the total HC emissions from LDG's. The following expression for calculating evaporative and crankcase HC emissions is also from Section 3.1.2 of AP-42:

$$f_n = \sum_{i=n-12}^{n+1} h_i m_i$$

where:

f_n = The combined evaporative and crankcase hydrocarbon emission factor for calendar year (n)

h_i = The combined evaporative and crankcase emission rate for the i^{th} model year

m_i = The weighted annual travel of the i^{th} model year during calendar year (n)

In order to calculate the precision of the emission factor, the precisions of c_i, d_i, m_i, s_i, and h_i must first be determined.

3.3.1.1 Deterioration factor, d_i - Factors to account for deterioration of exhaust control devices were obtained from Table 3.1.2-5 of AP-42. To calculate the precision of the deterioration factors (and also of other terms used to calculate the emission factor) we consulted the references used to develop the factors. A report of the California Air Resources Laboratory[31] is cited with respect to calculation of deterioration factors. This report presents graphs of HC and CO emissions versus mileage for California automobiles of model years 1966 through 1970. Deterioration factors for each model year are calculated by dividing the emissions at a certain vehicle age (as determined by mileage levels) by the emissions at age zero. The relationship between age and mileage[a] is given as:

Vehicle Age (Years)	0	1	2	3	4	5	6
Mileage (thousands of miles)	4.0	17.5	33.6	46.8	58.2	69.9	79.9

In addition to the graphs, the report gives gross regression data by model year and manufacturer at various mileages. These data (value, upper and lower limits) are interpreted to mean that the upper limit minus the value, divided by two equals the standard deviation of the value. We calculated a weighted average of the standard deviation using the weighting factors given in the reference as a basis for the graphs of emissions versus mileage:

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a) Data obtained from D. Kircher, U.S. EPA, March 9, 1973.

	Fraction of Total Sales
Chrysler	0.16
Ford	0.34
General Motors	0.50

The weighted standard deviation was then based on this formula:

$$S_{x\text{-mileage}} = [(W_c)^2(S_c)^2+(W_f)^2(S_f)^2+(W_g)^2(S_g)^2]^{1/2}$$

where W_c, W_f, and W_g = weighting factors for Chrysler, Ford, and GM, respectively.

S_c, S_f, and S_g = standard deviations for Chrysler, Ford, and GM, respectively.

The variance at X-miles was:

$$\text{Var (X-miles)} = \left[S_x - \text{miles}\right]^2$$

Since the formula for the deterioration factor, d, is

$$d_{(\text{age})} = \frac{\text{Value}_{\text{x-miles}}}{\text{Value}_{4000}}$$

the formula for variance of the deterioration factor, Var(d), is:

$$\text{Var(d)} = (d)^2\left[\frac{\text{Var}(4000)}{(\text{Value}_{4000})^2} + \frac{\text{Var (x-miles)}}{(\text{Value}_{\text{x-miles}})^2}\right]$$

Table 3.5 summarizes the variance of deterioration factors; Table 3.6 through 3.11 show the calculations performed for model years 1968 through 1970.

Reference 31 does not provide enough data for calculation of precision of the deterioration factors for NO_x emissions. It presents a graph of 1971 model year vehicle emissions versus mileage, but gives no gross regression data for that graph. EPA used the 1971 California NO_x data in the report in compiling 1973 nationwide (except California) NO_x deterioration factors. We estimated that the average precisions of the HC and CO deterioration factors for 1973 model cars at age 1 year would give

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Table 3.5 VARIANCE OF DETERIORATION FACTOR, d_i

		CO			(Exhaust) HC		
Age	Model year	d_i	$Var(d_i)$	$\frac{Var(d_i)}{(d_i)^2}$	d_i	$Var(d_i)$	$\frac{Var(d_i)}{(d_i)^2}$
1	1973	1.18	0.00309	0.00222	1.05	0.000662	0.00060
2	1972	1.32	0.00517	0.00297	1.10	0.000984	0.00081
3	1971	1.38	0.00617	0.00324	1.13	0.00134	0.00105
4	1970	1.40	0.00633	0.00323	1.15	0.00133	0.00100
5	1969	1.68	0.00220	0.00078	1.23	0.000507	0.00034
6	1968	1.58	0.00153	0.00061	1.28	0.000441	0.00027
7	1967	1.00	0.0	0.0	1.00	0.0	0.0
8	1966	1.00	0.0	0.0	1.00	0.0	0.0
9	1965	1.00	0.0	0.0	1.00	0.0	0.0
10	1964	1.00	0.0	0.0	1.00	0.0	0.0
11	1963	1.00	0.0	0.0	1.00	0.0	0.0
12	1962	1.00	0.0	0.0	1.00	0.0	0.0
≥13	1961 & older	1.00	0.0	0.0	1.00	0.0	0.0

Table 3.6 CALCULATION OF VARIANCE OF DETERIORATION FACTOR: CO, 1970

Vehicle age	Mileage	Chrysler				Ford				GM			
		Value	Upper	d_m	S_c	Value	Upper	d_m	S_f	Value	Upper	d_m	S_g
0	4,000	0.61	0.70	0.09	0.045	0.064	0.70	0.06	0.03	0.79	0.85	0.06	0.03
1	17,500	0.70	0.86	0.16	0.08	0.82	0.92	0.10	0.05	0.89	0.99	0.10	0.05
2	33,600	0.74	0.96	0.22	0.11	0.92	1.05	0.13	0.065	0.93	1.07	0.14	0.07
3	46,800	0.77	1.02	0.25	0.125	0.97	1.12	0.15	0.075	0.96	1.11	0.15	0.075
4	58,200	0.80	1.05	0.25	0.125	1.00	1.16	0.16	0.08	0.99	1.14	0.15	0.075

Vehicle age	S_x	Var(x)	Weighted value	Deterioration factor, d	Var(d)
0	0.020	0.00038	0.72	1.00	0.0
1	0.033	0.00108	0.85	1.18	0.00309
2	0.045	0.00202	0.95	1.32	0.00517
3	0.050	0.00246	0.99	1.38	0.00617
4	0.050	0.00255	1.01	1.40	0.00633

Where: d_m = (Upper - Value) and S_c, S_f, and $S_g = \frac{dm}{2}$

$\left[\mathrm{Var}(x)\right]^{1/2} = S_x = \left[W_c{}^2 S_c{}^2 + W_f{}^2 S_f{}^2 + W_g{}^2 S_g{}^2\right]^{1/2}$ and $W_c = 0.16$, $W_f = 0.34$, $W_g = 0.50$

$$\mathrm{Var}(d_a) = d_a{}^2 \left[\frac{\mathrm{Var}(4000)}{(\mathrm{Value}_{4000})^2} + \frac{\mathrm{Var}(m)}{(\mathrm{Value}_m)^2}\right] \quad \text{when} \quad d_a = \frac{\mathrm{WT.\ Value}_m}{\mathrm{WT.\ Value}_{4000}}$$

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Table 3.7 CALCULATION OF VARIANCE OF DETERIORATION FACTOR: CO, 1969

Vehicle age	Mileage	Chrysler				Ford				GM			
		Value	Upper	d_m	S_c	Value	Upper	d_m	S_f	Value	Upper	d_m	S_g
0	4,000	0.89	0.97	0.08	0.040	0.70	0.74	0.04	0.02	1.15	1.20	0.05	0.025
5	69,900	1.24	1.41	0.17	0.085	1.07	1.17	0.10	0.05	1.64	1.74	0.10	0.050

Vehicle age	S_x	Var(x)	Weighted value	Deterioration factor, d	Var(d)
0	0.016	0.000243	0.90	1.00	
5	0.033	0.0011	1.51	1.68	0.00220

Where: d_m = (Upper - Value) and S_c, S_f, and $S_g = \frac{dm}{2}$

$$\left[\mathrm{Var}(x)\right]^{1/2} = S_x = \left[W_c^2 S_c^2 + W_f^2 S_f^2 + W_g^2 S_g^2\right]^{1/2} \quad \text{and } W_c = 0.16,\ W_f = 0.34,\ W_g = 0.50$$

$$\mathrm{Var}(d_a) = d_a^2 \left[\frac{\mathrm{Var}(4000)}{(\mathrm{Value}_{4000})^2} + \frac{\mathrm{Var}(m)}{(\mathrm{Value}_m)^2}\right] \quad \text{when} \quad d_a = \frac{\mathrm{WT.\ Value}_m}{\mathrm{WT.\ Value}_{4000}}$$

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Table 3.8 CALCULATION OF VARIANCE OF DETERIORATION FACTOR: CO, 1968

Vehicle age	Mileage	Chrysler				Ford				GM			
		Value	Upper	d_m	S_c	Value	Upper	d_m	S_f	Value	Upper	d_m	S_g
0	4,000	0.99	1.05	0.06	0.03	0.93	0.99	0.06	0.03	1.15	1.20	0.05	0.025
6	79,900	1.42	1.52	0.10	0.05	1.40	1.52	0.12	0.06	1.79	1.87	0.08	0.04

Vehicle age	S_x	Var(x)	Weighted value	Deterioration factor, d	Var(d)
0	0.017	0.000283	1.02		
6	0.030	0.00088	1.61	1.58	0.00153

Where: d_m = (Upper - Value) and S_c, S_f, and $S_g = \frac{dm}{2}$

$\left[\text{Var}(x)\right]^{1/2} = S_x = \left[W_c^2 S_c^2 + W_f^2 S_f^2 + W_g^2 S_g^2\right]^{1/2}$ and $W_c = 0.16$, $W_f = 0.34$, $W_g = 0.50$

$$\text{Var}(d_a) = d_a^2 \left[\frac{\text{Var}(4000)}{(\text{Value}_{4000})^2} + \frac{\text{Var}(m)}{(\text{Value}_m)^2}\right] \quad \text{when} \quad d_a = \frac{\text{WT. Value}_m}{\text{WT. Value}_{4000}}$$

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Table 3.9 CALCULATION OF VARIANCE OF DETERIORATION FACTOR: HC, 1970

Vehicle age	Mileage	Chrysler				Ford				GM			
		Value	Upper	d_m	S_c	Value	Upper	d_m	S_f	Value	Upper	d_m	S_g
0	4,000	172	183	11	5.5	185	192	8	4.0	171	179	8	4.0
1	17,500	185	202	17	8.5	201	213	12	6.0	200	212	12	6.0
2	33,600	191	214	23	11.5	210	226	16	8.0	214	229	15	7.5
3	46,800	194	220	26	13.0	214	232	18	9.0	221	240	19	9.5
4	58,200	198	225	27	13.5	218	235	17	8.5	226	245	19	9.5

Vehicle age	S_x	Var(x)	Weighted value	Deterioration factor, d	Var(d)
0	2.57	6.62	183		
1	3.87	15.01	193	1.05	0.000662
2	4.98	24.85	201	1.10	0.000984
3	6.02	36.25	206	1.13	0.00134
4	5.96	35.58	210	1.15	0.00133

Where: d_m = (Upper - Value) and S_c, S_f, and $S_g = \frac{dm}{2}$

$\left[\mathrm{Var}(x)\right]^{1/2} = S_x = \left[W_c{}^2 S_c{}^2 + W_f{}^2 S_f{}^2 + W_g{}^2 S_g{}^2\right]^{1/2}$ and $W_c = 0.16$, $W_f = 0.34$, $W_g = 0.50$

$$\mathrm{Var}(d_a) = d_a{}^2 \left[\frac{\mathrm{Var}(4000)}{(\mathrm{Value}_{4000})^2} + \frac{\mathrm{Var}(m)}{(\mathrm{Value}_m)^2}\right] \quad \text{when} \quad d_a = \frac{\mathrm{WT.\ Value}_m}{\mathrm{WT.\ Value}_{4000}}$$

Table 3.10 CALCULATION OF VARIANCE OF DETERIORATION FACTOR: HC, 1969

Vehicle age	Mileage	Chrysler				Ford				GM			
		Value	Upper	d_m	S_c	Value	Upper	d_m	S_f	Value	Upper	d_m	S_g
0	4,000	244	255	11	5.5	249	257	8	4.0	235	242	7	3.5
5	69,900	322	345	23	11.5	290	305	15	7.5	286	299	13	6.5

Vehicle age	S_x	Var(x)	Weighted value	Deterioration factor, d	Var(d)
0	2.38	5.69	240		
5	4.52	20.5	295	1.23	0.000507

Where: d_m = (Upper - Value) and S_c, S_f, and $S_g = \frac{dm}{2}$

$\left[\mathrm{Var}(x)\right]^{1/2} = S_x = \left[W_c^2 S_c^2 + W_f^2 S_f^2 + W_g^2 S_g^2\right]^{1/2}$ and $W_c = 0.16$, $W_f = 0.34$, $W_g = 0.50$

$$\mathrm{Var}(d_a) = d_a^2 \left[\frac{\mathrm{Var}(4000)}{(\mathrm{Value}_{4000})^2} + \frac{\mathrm{Var}(m)}{(\mathrm{Value}_m)^2}\right] \quad \text{when} \quad d_a = \frac{\mathrm{WT.\ Value}_m}{\mathrm{WT.\ Value}_{4000}}$$

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Table 3.11 CALCULATION OF VARIANCE OF DETERIORATION FACTOR: HC, 1968

Vehicle age	Mileage	Chrysler				Ford				GM			
		Value	Upper	d_m	S_c	Value	Upper	d_m	S_f	Value	Upper	d_m	S_g
0	4,000	255	263	8	4.0	270	279	9	4.5	260	268	8	4.0
6	79,000	330	344	14	7.0	337	350	13	6.5	348	360	12	6.0

Vehicle age	S_x	Var(x)	Weighted value	Deterioration factor, d	Var(d)
0	3.00	9.00	260		
6	3.89	15.1	333	1.28	0.000441

Where: d_m = (Upper - Value) and S_c, S_f, and $S_g = \frac{dm}{2}$

$$\left[\mathrm{Var}(x)\right]^{1/2} = S_x = \left[W_c^2 S_c^2 + W_f^2 S_f^2 + W_g^2 S_g^2\right]^{1/2} \quad \text{and } W_c = 0.16,\ W_f = 0.34,\ W_g = 0.50$$

$$\mathrm{Var}(d_a) = d_a^2 \left[\frac{\mathrm{Var}(4000)}{(\mathrm{Value}_{4000})^2} + \frac{\mathrm{Var}(m)}{(\mathrm{Value}_m)^2}\right] \quad \text{when} \quad d_a = \frac{\mathrm{WT.\ Value}_m}{\mathrm{WT.\ Value}_{4000}}$$

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a good approximation of the precision of the NO_x deterioration factor for a vehicle of the same model and age. We analyzed data from the Six Cities Report[32] to determine whether a pattern developed among precisions for HC, CO, and NO_x. Since no trend was found, we decided to use the average precision of HC and CO deterioration factors as the precision of the NO_x deterioration factor, as follows:

		$(\text{Precision})^2 = \frac{\text{Var}(d_i)}{(d_i)^2}$		
Age	Model Year	HC	CO	Ave = NO_x
1	1973	0.00060	0.00222	0.00141

On this basis, the NO_x deterioration factor for 1973 model cars 1 year old is 1.11, and the precision of that factor equals 0.0375.

3.3.1.2 1975 Federal Test Procedure Emission Rate, c_i - Exhaust emission factors at low mileage per model year (c_i) are given in Table 3.1.2-1 of AP-42. These factors were calculated with test data from the Six Cities Report (Reference 32) and the deterioration factors (Reference 31).

The exhaust emission rates for pre-1968 vehicles at low altitudes are the average of test data from pre-1968 model cars in five of the six test cities (excluding Denver). Since these vehicles were not subject to deterioration of exhaust control devices, no deterioration factors were applied to obtain low-mileage emission rates. Hence the variance of the emission rates for pre-1968 model vehicles was calculated from the average standard deviation of all pre-1968 data and the number of observations in the Six Cities Report of the corresponding model year. Tables 3.12 through 3.14 show the variance of the emission rates for pre-1968 automobiles, by pollutant.

The low-mileage HC and CO emission rates for 1968 through 1971 model cars were calculated by dividing emission values for vehicles in the five low-altitude cities by the appropriate deterioration factor. No deterioration factor was applied to NO_x emission rates, since the vehicles had no NO_x controls.

The precision of the emission rates for 1968 through 1971 model cars inlcudes both the precision of the test data from the Six Cities Report and the precision of the deterioration factor used to project low-mileage emissions (except for NO_x). We calculated the precision of the Six Cities test data using the standard deviations, S, of the test results. We then calculated the standard deviation of the mean, $S_{\bar{x}}$, by dividing S by the square root of the number of observations, and calculated precision by dividing $S_{\bar{x}}$ by the emission factor. These calculations are summarized in Table 3.15.

Precision of the deterioration factors were calculated according to the procedure described in the preceding section. Calculations of the precisions of deterioration factors not given earlier are shown in Tables 3.16 through 3.19.

Variance of the low-mileage emission rate, c_i, where:

$$c_i = \frac{\text{Six Cities Data}}{\text{Deterioration Factor}}$$

was calculated by the formula:

$$\text{Var}(c_i) = (c_i)^2 \left[\frac{\text{Var (Six Cities)}}{(\text{Value}_{\text{Six Cities}})^2} + \frac{\text{Var }(d_i)}{(d_i)^2}\right]$$

Table 3.12 ANALYSIS OF SIX CITIES DATA: PRE-1968, CO

Average Emission Factor, c_i = 87[a]

Average Standard Deviation, S = 40.41[b]

Model year	Emission factor, C_i	N	S_x	Var(C_i)
1967	87	71	4.796	23.0
1966	87	83	4.436	19.7
1965	87	80	4.518	20.4
1964	87	64	5.051	25.5
1963	87	55	5.449	29.7
1962	87	38	6.556	43.0
1961 & older	87	100	4.041	16.3

Where:

N = Number of test observations at low altitude found in Reference 32 of the corresponding model year.

$$S_{\bar{x}} = \frac{S}{n}$$

$$\mathrm{Var}(C_i) = (S_{\bar{x}})^2$$

a) Taken from AP-42 (Reference 30).

b) Calculated from data presented in Reference 32.

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Table 3.13 ANALYSIS OF SIX CITIES DATA: PRE-1968, HC

Average Emission Factor, c_i = 8.8[a]

Average Standard Deviation, S = 7.47[b]

Model year	Emission factor, C_i	N	S_x	$Var(C_i)$
1967	8.8	71	0.087	0.786
1966	8.8	83	0.820	0.672
1965	8.8	80	0.835	0.698
1964	8.8	64	0.934	0.872
1963	8.8	55	1.007	1.015
1962	8.8	38	1.212	1.469
1961 & older	8.8	100	0.747	0.558

Where:

N = Number of test observations at low altitude found in Reference 32 of the corresponding model year.

$$S_{\bar{x}} = \frac{S}{n}$$

$$Var(C_i) = (S_{\bar{x}})^2$$

a) Taken from AP-42 (Reference 30).

b) Calculated from data presented in Reference 32.

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Table 3.14 ANALYSIS OF SIX CITIES DATA: PRE-1968, NO_x

Average Emission Factor, c_i = 3.6[a]

Average Standard Deviation, S = 1.89[b]

Model year	Emission factor, C_i	N	S_x	$Var(C_i)$
1967	3.6	71	0.224	0.0503
1966	3.6	83	0.207	0.0430
1965	3.6	80	0.211	0.0447
1964	3.6	64	0.236	0.0558
1963	3.6	55	0.255	0.0650
1962	3.6	38	0.307	0.0940
1961 & older	3.6	100	0.189	0.0357

Where:

N = Number of test observations at low altitude found in Reference 32 of the corresponding model year.

$$S_{\bar{x}} = \frac{S}{n}$$

$$Var(C_i) = (S_{\bar{x}})^2$$

a) Taken from AP-42 (Reference 30).

b) Calculated from data presented in Reference 32.

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Table 3.15 ANALYSIS OF SIX CITIES DATA, 1968-1971

	HC		CO		NO_x	
Year	$\sigma\bar{x}=\frac{\sigma}{\sqrt{n}}$	$\frac{\sigma\bar{x}}{\bar{x}}\left[100\right]=\%$	$\sigma\bar{x}=\frac{\sigma}{\sqrt{n}}$	$\frac{\sigma\bar{x}}{\bar{x}}\left[100\right]=\%$	$\sigma\bar{x}=\frac{\sigma}{\sqrt{n}}$	$\frac{\sigma\bar{x}}{\bar{x}}\left[100\right]=\%$
1971	0.125	4.08	2.436	6.07	0.177	3.68
1970	0.210	5.38	2.660	5.52	0.180	3.56
1969	0.453	8.73	3.289	5.33	0.214	3.92
1968	0.777	13.97	6.298	9.25	0.211	4.86
Pre-1968	0.337	3.92	1.824	2.14	0.0853	2.41

$$c_i = \frac{\text{Six cities test data}}{\text{deterioration factor}}$$

$$\mathrm{Var}(c_i) = (c_i)^2 \left[\frac{(\sigma\bar{x}_{\text{six cities}})^2}{(\bar{x}_{\text{six cities}})^2} + \frac{\mathrm{Var}(d_i)}{(d_i)^2}\right]$$

$$\mathrm{Var}(c_i) = (\sigma\bar{x})^2$$

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Table 3.16 CALCULATION OF VARIANCE OF DETERIORATION FACTOR: HC, 1969

Vehicle age	Mileage	Chrysler				Ford				GM			
		Value	Upper	d_m	S_c	Value	Upper	d_m	S_f	Value	Upper	d_m	S_g
0	4,000	244	255	11	5.5	249	257	8	4.0	235	242	7	3.5
3	46,800	310	332	22	11.0	279	294	15	7.5	275	287	12	6.0

Vehicle age	S_x	Var(x)	Weighted value	Deterioration factor, d	Var(d)
0	2.38	5.69	240		
3	4.31	18.6	283	1.18	0.000461

Where: $d_m = (\text{Upper} - \text{Value})$ and S_c, S_f, and $S_g = \frac{dm}{2}$

$$\left[\text{Var}(x)\right]^{1/2} = S_x = \left[W_c^2 S_c^2 + W_f^2 S_f^2 + W_g^2 S_g^2\right]^{1/2} \quad \text{and } W_c = 0.16,\ W_f = 0.34,\ W_g = 0.50$$

$$\text{Var}(d_a) = d_a^2 \left[\frac{\text{Var}(4000)}{(\text{Value}_{4000})^2} + \frac{\text{Var}(m)}{(\text{Value}_m)^2}\right] \quad \text{when} \quad d_a = \frac{\text{WT. Value}_m}{\text{WT. Value}_{4000}}$$

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Table 3.17 CALCULATION OF VARIANCE OF DETERIORATION FACTOR: HC, 1968

Vehicle age	Mileage	Chrysler				Ford				GM			
		Value	Upper	d_m	S_c	Value	Upper	d_m	S_f	Value	Upper	d_m	S_g
0	4,000	255	263	8	4.0	270	279	9	4.5	260	268	8	4.0
4	58,200			14	7.0			13	6.5			12	6.0

Vehicle age	S_x	Var(x)	Weighted value	Deterioration factor, d	Var(d)
0	3.00	9.00	260		
4	3.89	15.1	320	1.23	0.000424

Where: $d_m = (\text{Upper} - \text{Value})$ and S_c, S_f, and $S_g = \frac{dm}{2}$

$$\left[\text{Var}(x)\right]^{1/2} = S_x = \left[W_c^2 S_c^2 + W_f^2 S_f^2 + W_g^2 S_g^2\right]^{1/2} \quad \text{and } W_c = 0.16,\ W_f = 0.34,\ W_g = 0.50$$

$$\text{Var}(d_a) = d_a^2 \left[\frac{\text{Var}(4000)}{(\text{Value}_{4000})^2} + \frac{\text{Var}(m)}{(\text{Value}_m)^2}\right] \quad \text{when} \quad d_a = \frac{\text{WT. Value}_m}{\text{WT. Value}_{4000}}.$$

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Table 3.18 CALCULATION OF VARIANCE OF DETERIORATION FACTOR: CO, 1969

Model year - 1969

Pollutant - CO

Vehicle age	Mileage	Chrysler				Ford				GM			
		Value	Upper	d_m	S_c	Value	Upper	d_m	S_f	Value	Upper	d_m	S_g
0	4,000	0.89	0.97	0.08	0.04	0.70	0.74	0.04	0.02	1.15	1.20	0.05	0.025
3	46,800	1.17	1.34	0.17	0.085	1.00	1.10	0.10	0.05	1.57	1.66	0.09	0.045

Vehicle age	S_x	Var(x)	Weighted value	Deterioration factor, d	Var(d)
0	0.016	0.000243	0.90		
3	0.031	0.00098	1.43	1.59	0.00200

Where: $d_m = (\text{Upper} - \text{Value})$ and S_c, S_f, and $S_g = \frac{dm}{2}$

$$\left[\text{Var}(x)\right]^{1/2} = S_x = \left[W_c^2 S_c^2 + W_f^2 S_f^2 + W_g^2 S_g^2\right]^{1/2} \quad \text{and } W_c = 0.16,\ W_f = 0.34,\ W_g = 0.50$$

$$\text{Var}(d_a) = d_a^2 \left[\frac{\text{Var}(4000)}{(\text{Value}_{4000})^2} + \frac{\text{Var}(m)}{(\text{Value}_m)^2}\right] \quad \text{when} \quad d_a = \frac{\text{WT. Value}_m}{\text{WT. Value}_{4000}}$$

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Table 3.19 CALCULATION OF VARIANCE OF DETERIORATION FACTOR: CO, 1968

Vehicle age	Mileage	Chrysler				Ford				GM			
		Value	Upper	d_m	S_c	Value	Upper	d_m	S_f	Value	Upper	d_m	S_g
0	4,000	0.99	1.05	0.06	0.03	0.93	0.99	0.06	0.03	1.15	1.20	0.05	0.025
4	58,200			0.10	0.05			0.12	0.06			0.08	0.04

Vehicle age	S_x	Var(x)	Weighted value	Deterioration factor, d	Var(d)
0	0.017	0.000283	1.02		
4	0.030	0.00088	1.50	1.47	0.00147

Where: d_m = (Upper - Value) and S_c, S_f, and $S_g = \frac{dm}{2}$

$\left[\text{Var}(x)\right]^{1/2} = S_x = \left[W_c^{\,2} S_c^{\,2} + W_f^{\,2} S_f^{\,2} + W_g^{\,2} S_g^{\,2}\right]^{1/2}$ and $W_c = 0.16$, $W_f = 0.34$, $W_g = 0.50$

$$\text{Var}(d_a) = d_a^{\,2} \left[\frac{\text{Var}(4000)}{(\text{Value}_{4000})^2} + \frac{\text{Var}(m)}{(\text{Value}_m)^2}\right] \quad \text{when} \quad d_a = \frac{\text{WT. Value}_m}{\text{WT. Value}_{4000}}$$

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Table 3.20 gives variances of the low-mileage emission rates, $Var(c_i)$ for vehicles of model years 1968 through 1973. Since these emission rates were based upon the relation of low-mileage emissions to standards for 1971 and earlier controlled vehicles, the precisions of rates for the 1972 and 1973 models are assumed to equal the precision of 1971 emission rate. Note that basing 1972 and 1973 emission rates on the relation of 1971 emission rates to standards affects the accuracy of the 1972 and 1973 emission rates but does not affect the precision. The following equation was used for that calculation:

$$\frac{Var\ (c_{1972})}{(c_{1972})^2} = \frac{Var\ (c_{1971})}{(c_{1971})^2}$$

3.3.1.3 Weighted annual travel, M_i - The factors for weighted annual travel, M_i, are given in Table 3.1.2-7 of AP-42. These factors were calculated by the formula $M = \frac{ab}{\Sigma ab}$, where a is the fraction of total vehicle miles nationwide (by vehicle age) and b is the average annual miles driven (also by vehicle age). The precision of M_i depends upon the precision of values for the fraction of vehicles in use and for the average annual miles driven.

Values for the fraction of vehicles in use nationwide are obtained from Automobile Facts and Figures.[19] These numbers are very precise, since they are obtained from tabulation of nationwide registration figures. Calculation of automobile emissions for any jurisdiction within the United States could

Table 3.20 VARIANCE OF EMISSION RATE, 1968-1973

Model year	CO		HC		NO_x	
	c_i*	Var(Ci)	c_i	Var(Ci)	c_i	Var(Ci)
1968	46	19.6	4.5	0.401	4.3	0.0445
1969	39	5.48	4.4	0.153	5.5	0.0458
1970	36	7.79	3.6	0.0483	5.1	0.0324
1971	34	6.88	2.9	0.0192	4.8	0.0313
1972[a]	19	2.15	2.7	0.0166	4.8	0.0313
1973[a]	19	2.15	2.7	0.0166	2.3	0.00719

a) 1972 and 1973 rate based upon relationship of low mileage 1971 emissions to standards for 1971 and earlier vehicles. Therefore precision of 1972 and 1973 emission rates equal precision of 1971 emission rate.

Therefore:

$$\frac{\mathrm{Var}(C_{1972})}{(C_{1972})^2} = \frac{\mathrm{Var}(C_{1971})}{(C_{1971})^2}$$

*Emission rate

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incorporate registration data from that jurisdiction in lieu of the nationwide figures to determine the fraction of vehicles in use. The precision of the value for fraction of vehicles in use, whether calculated from nationwide or jurisdictional data, is the same since both are based on registration data. The precision value would be very low, based on the assumption that registration data are very precise. Therefore the precision of the value for fraction of vehciles in use is neglected in calculating the precision of the annual travel value, since the precision of the value for annual miles driven will dominate.

The reference for average annual miles driven is a Nationwide Personal Transportation Study[3] of the Department of Transportation. Data from this study are plotted on Figure 3.2 along with the results of least-squares straight-line fit. The variances of the points on this line can be determined by first calculating the standard error of estimate, Sy.x, where:

$$Sy.x = \left[\frac{1}{N-2} \left(\Sigma Y^2 - a\Sigma Y - b\Sigma XY \right) \right]^{1/2}$$

and

$$b = \frac{N\Sigma XY - \Sigma X\Sigma Y}{N\Sigma X^2 - (\Sigma X)^2} \,, \quad a = \frac{\Sigma Y}{N} - b\,\frac{\Sigma X}{N}$$

Performing this calculation yields:

$$Sy.x = 1337 \text{ miles/vehicle}$$

The variances of the points on the line are then calculated by the equation:

$$Var(y) = (Sy.x)^2 \left[\frac{1}{N} + \frac{(X - \bar{X})^2}{(X - \bar{X})^2} \right]$$

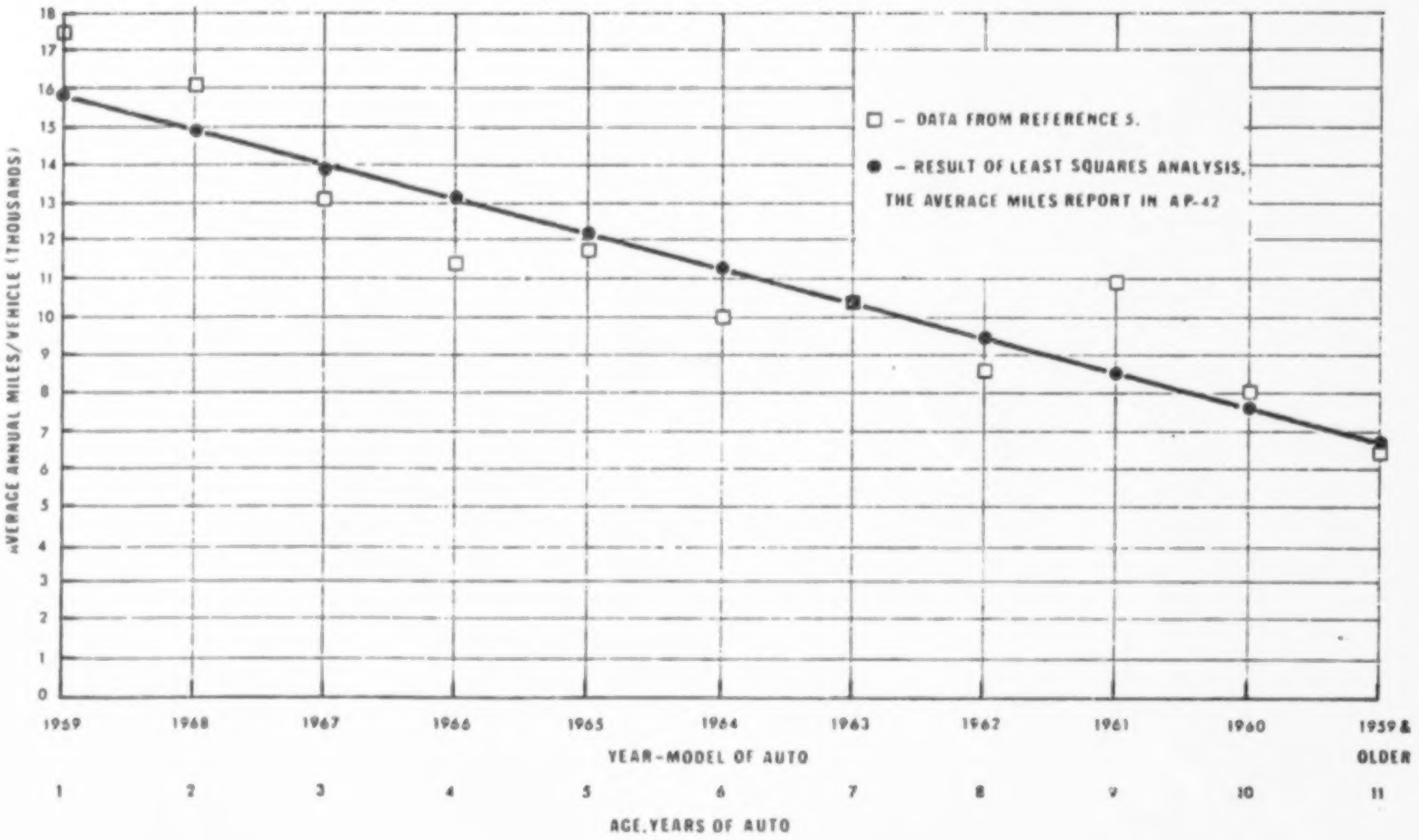

Figure 3.2
Average Annual Miles Driven

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These values, Var(y) are the values for the variance of the annual miles driven (b), or Var(b). Table 3.21 shows the calculation of Var(b).

The variance of the value for weighted annual travel, $\mathrm{Var}(M_i)$ is then calculated:

$$\mathrm{Var}(M_i) = M_i^{\,2}\left[\frac{\mathrm{Var}(a_i b_i)}{(a_i\ b_i)^2} + \frac{\mathrm{Var}\ (\Sigma a_i b_i)}{(\Sigma a_i b_i)^2}\right]$$

Table 3.22 shows the calculation of Var (M_i).

3.3.1.4 Weighted speed adjustment factor, s_i - The equation for the speed adjustment factor (from AP-42) is:

$$s_i = \sum_{j=1}^{n} f_j v_j$$

where: s_i = The weighted speed adjustment factor for the i^{th} model year

f_j = The fraction of total annual vehicle miles traveled at speed (j)

v_j = The vehicular average speed correction factor for average speed (j)

In this project, however, the emission factors in the NEDS computer are segregated by road type (indicated by average speed driven on the roads). Therefore in calculation for purposes of this report, f_i equals 1, thus s_i equals v_j. The average speed correction factor, V, is given in Figure 3.1.1-1 of AP-42. The reference for CO and HC correction factors is McMichael and Rose,[34] who present log graphs of CO and HC emissions versus average route speed, indicating a range of ± two units of the standard error of estimate.

To calculate the precision of any point on the graph, the standard error of the estimated value, $S\hat{y}$, is needed:

Table 3.21 VARIANCE OF ANNUAL MILES DRIVEN

x	$(x-\bar{x})^2$	$\frac{(x-\bar{x})^2}{\Sigma(x-\bar{x})^2}$	$\frac{1}{n} + \frac{(x-\bar{x})^2}{\Sigma(x-\bar{x})^2}$	Var(y) y =1000 miles	y = miles
0	36	.3273	.4182	.748	748,000
1	25	.2273	.3182	.568	568,000
2	16	.1454	.2363	.422	422,000
3	9	.0818	.1727	.308	308,000
4	4	.0364	.1273	.241	241,000
5	1	.0091	.1000	.179	179,000
6	0	0	.0909	.162	162,000
7	1	.0091	.1000	.179	179,000
8	4	.0364	.1273	.241	241,000
9	9	.0818	.1727	.308	308,000
10	16	.1454	.2363	.422	422,000
11	25	.2273	.3182	.568	568,000
12	36	.3273	.4182	.748	748,000
13	49	.4454	.5363	.959	959,000

$\Sigma(x-\bar{x})^2 = 110$

$n = 11$

$\mathrm{Var}(y) = Sy.x^2 \left[\frac{1}{n} + \frac{(x-\bar{x})^2}{\Sigma(x-\bar{x})^2}\right]$

$Sy.x = 1.337$

$Sy.x^2 = 1.788$

Table 3.22 VARIANCE OF WEIGHTED ANNUAL TRAVEL, $\mathrm{Var}(m_i)$

Age	Fract. in use (a)	Ave. travel (b)	Var(b)	a x b	Var(ab)	$(a \times b)^2$	m	$\frac{\mathrm{Var}(ab)}{(ab)^2}$	$\frac{\mathrm{Var}\Sigma(ab)}{[\Sigma(ab)]^2}$	$\mathrm{Var}(m) = m^2$	$\left[\frac{\mathrm{Var}(ab)}{(ab)^2} + \frac{\mathrm{Var}\Sigma(ab)}{[\Sigma(ab)]^2}\right]$
0	0.000	15,900	748,000	0	0	0	.000	0	.00021	0	
1	.078	15,900	568,000	1240	3455	1,537,600	.107	.00224	.00021	.0000281	
2	.116	15,000	422,000	1740	5678	3,027,600	.151	.00188	.00021	.0000477	
3	.110	14,000	308,000	1540	3727	2,371,600	.133	.00157	.00021	.0000315	
4	.099	13,100	241,000	1284	2315	1,648,656	.111	.00140	.00021	.0000198	
5	.106	12,200	179,000	1293	2011	1,671,849	.112	.00120	.00021	.0000177	
6	.106	11,300	162,000	1198	1821	1,435,204	.104	.00127	.00021	.0000160	
7	.088	10,300	179,000	906	1385	820,836	.078	.00169	.00021	.0000116	
8	.078	9,400	241,000	733	1465	537,289	.063	.00273	.00021	.0000117	
9	.063	8,500	308,000	536	1225	287,296	.046	.00426	.00021	.0000095	
10	.041	7,600	422,000	312	711	97,344	.027	.00730	.00021	.0000055	
11	.035	6,700	568,000	235	699	55,225	.020	.01266	.00021	.0000051	
12	.021	6,700	748,000	141	331	19,881	.012	.01665	.00021	.0000024	
≥13	.060	6,700	959,000	402	3452	161,604	.036	.02136	.00021	.0000280	
			TOTALS:	11560	28275	13,671,984					

$$\mathrm{Var}(ab) = (ab)^2 \ \frac{\mathrm{Var}(b)}{b^2}$$

$$\mathrm{Var}(\Sigma ab) = \Sigma \mathrm{Var}(ab)$$

$$\frac{\mathrm{Var}\Sigma(ab)}{[\Sigma(ab)]^2} = \frac{28275}{(11560)^2} = .00021$$

$$\mathrm{Var}(m) = m^2 \left[\frac{\mathrm{Var}(ab)}{(ab)^2} + \frac{\mathrm{Var}\Sigma(ab)}{[\Sigma(ab)]^2}\right] \quad \text{where } m = \frac{ab}{\Sigma ab}$$

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$$S\hat{y} = Sy.x\left[\frac{1}{N} + \frac{(X_o-\bar{X})^2}{\Sigma(X - \bar{X})^2}\right]$$

but $(X_o-\bar{X})^2$ and $\Sigma(X-\bar{X})^2$ cannot be determined without the original data. For the purpose of this study, it is assumed that:

$$\frac{(X_o-\bar{X})^2}{\Sigma(X-\bar{X})^2} << \frac{1}{N}$$

hence the term $\frac{(X_o-\bar{X})^2}{\Sigma(X-\bar{X})^2}$ is dropped from the equation, which is simplified:

$$S\hat{y} = \frac{Sy.x}{\sqrt{N}}$$

The standard error of estimate (Sy.x) is read from the graph in reference 34. It is one-half the range shown of plus two units of the standard error of estimate. The graphs used for the correction factors are based on combined data from Cincinnati and Los Angeles.

From the calculations of $S\hat{y}$, the precision of any point on the curve is calculated by the formula:

$$P = \frac{\text{antilog}\left[\log\hat{y} - S\hat{y}\right] - \hat{y}}{\hat{y}}.$$

where $\hat{y}$ is the estimated value. The precision value is the same for all points along the curve; results of the precision calculations are given below.

Pollutant	Precision of Any Point on the Curve
CO	0.0474
HC	0.0280

The speed correction factors are calculated by dividing the emission rates at 15, 30, 45, and 60 miles per hour by the emission rate at 19.6 miles per hour. The variance of the speed correction factor, $\mathrm{Var}(V_x)$, is calculated

$$\mathrm{Var}(V_x) = V_x^2\left[(P_{19.5})^2 + (P_x)^2\right]$$

Where $V_x = \dfrac{\text{Emissions}_{x\text{-mph}}}{\text{Emissions}_{19.5\text{ mph}}}$

and $P_{19.5} = P_x$ = Precision of any point on the graph. Table 3.23 shows the precisions of HC and CO speed correction factors.

Reference 32 is cited for the NO_x speed correction curve. Since this reference does not indicate how the NO_x speed correction curve was developed from the data, we were unable to calculate the precision of the NO_x speed correction factors. We therefore estimate that the precision of the NO_x speed correction factors would be equal to the average precision of the HC and CO speed correction factors.

Pollutant	Precision	$\frac{\mathrm{Var}(S_i)}{(S_i)^2}$
HC	0.0396	0.00157
CO	0.0670	0.00449
Ave = NO_x	0.0533	0.00303

3.3.1.5 Total Exhaust Emissions, e_n - The total exhaust emissions, e_n, and their precisions are calculated as follows:

$$e_i = c_i d_i m_i s_i$$

$$e_n = \Sigma e_i$$

Table 3.23 PRECISION OF SPEED CORRECTION CURVES FOR CO AND HC

	CO			HC		
Speed	Speed correction factor, V_j	$\mathrm{Var}(V_j)$	$\frac{\mathrm{Var}(V_j)}{(V_j)^2}$	Speed correction factor, V_j	$\mathrm{Var}(V_j)$	$\frac{\mathrm{Var}(V_j)}{(V_j)^2}$
25	0.81	0.00295	0.00449	0.87	0.00119	0.00157
35	0.60	0.00162	0.000449	0.68	0.000725	0.00157
45	0.50	0.00112	0.000449	0.58	0.000528	0.00157
55	0.44	0.000867	0.000449	0.50	0.000393	0.00157

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$$\mathrm{Var}(e_i) \;=\; (e_i)^2 \left[\frac{\mathrm{Var}(c_i)}{(c_i)^2} + \frac{\mathrm{Var}(d_i)}{(d_i)^2} + \frac{\mathrm{Var}(m_i)}{(m_i)^2} + \frac{\mathrm{Var}(s_i)}{(s_i)^2}\right]$$

$$\mathrm{Var}(e_i) \;=\; \Sigma\mathrm{Var}(e_i)$$

$$\text{Standard Deviation, } S_{e_n} \;=\; \left[\mathrm{Var}(e_n)\right]^{1/2}$$

$$\text{Precision} \;=\; \frac{S_{e_n}}{e_n}$$

Table 3.24 summarizes the precisions of exhaust emission factors for CO, HC, and NO_x. Tables E-1 through E-4, Tables E-5 through E-8, and Tables E-9 through E-12 of Appendix E show respectively the calculations of these precision values.

It is emphasized that the values given here represent the precision of the emission factors and not their accuracy. Although the large sample size upon which the data were based yields very good statistical precision, the data could be highly inaccurate as a characterization of a given population. The accuracy of the emission factors for any jurisdiction within the United States cannot be estimated from the available data.

3.3.1.6 Combined Evaporative and Crankcase Emission Rate, h_i - The combined evaporative and crankcase emission rates are given in Table 3.1.2-3 of AP-42. The precisions of the evaporative and the crankcase emission rates are therefore calculated separately to determine the precision of the combined emission rate.

The data for evaporative HC emissions from LDG's are from an interim report of General Motors Corporation.[35] Interpolating these data at 9.0 RVP, EPA investigators developed emission

Table 3.24 PRECISION OF LIGHT-DUTY GASOLINE-POWERED VEHICLES

Road type	Precision = $\frac{\sigma e}{e}$		
	CO	Exhaust HC	NO_x
Urban	0.036	0.035	0.028
Suburban	0.036	0.035	0.028
Rural	0.036	0.035	0.028
Limited access	0.036	0.035	0.028

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rates of 77.8 grams/(vehicle day) and 36.5 grams/(HEW test).[36,37] The precisions of these interpolated values are determined by calculating the standard error of the estimated value, Sy:

$$Sy = Sy \cdot x \left[\frac{1}{N} + \frac{(x_o - \bar{x})^2}{\Sigma (x - \bar{x})^2}\right]^{1/2}$$

In this equation, Sy·x is the standard error of estimate, calculated as follows:

$$Sy \cdot x = \frac{1}{N-2} [\Sigma Y^2 - a\Sigma Y - b\Sigma XY]^{1/2}$$

where:

$$b = \frac{N\Sigma XY - \Sigma X \Sigma Y}{N \Sigma X^2 - (\Sigma X)^2}$$

$$a = \frac{\Sigma Y}{N} - b \frac{\Sigma X}{N}$$

Performing the above calculations gives:

for $y = 77.8 \frac{\text{grams}}{\text{vehicle day}}$, $Sy = 3.27 \frac{\text{grams}}{\text{vehicle day}}$

for $y = 36.5 \frac{\text{grams}}{\text{HEW test}}$, $Sy = 1.22 \frac{\text{grams}}{\text{HEW test}}$

Calculation of LDG evaporative emissions also entails use of the figure of 26 miles driven per day, a value that approximates the nationwide average according to data of the Department of Transportation (Reference 19, page 57). Our earlier analysis of the precision of values for measured vehicle miles on the NEDS area source form (Section 3.2.2.9) indicated that values for the total annual miles driven by all passenger cars are precise within 3.2 percent. Therefore, since the number of vehicles registered is considered precise, the values for average annual miles traveled per vehicle and for average miles driven per day per vehicle are assigned a precision of 3.2 percent.

Evaporative emission rates for pre-1971 (uncontrolled) LDG's are calculated by dividing 77.8 grams/(vehicle day) by 26 miles/day, yielding emissions of 2.99 grams/mile. The nationwide limit on evaporative emissions from 1971 model LDG's was 6 grams/(HEW test).[36,37] The evaporative emission rate for that model year is calculated by dividing 77.8 grams/(vehicle day) by 36.5 grams/(HEW test), multiplying by 6 grams/(HEW test), and dividing by 26 miles/day. This procedure gives an emission rate of 0.49 gram/mile. Regulations for 1972 and newer LDG's limit evaporative emissions to 2 grams/(HEW test).[36] The emission rate for these vehicles is calculated as outlined above, using 2 grams/(HEW test) instead of 6 grams/(HEW test). The resulting emission rate is 0.16 gram/mile. Calculations of the variance of the evaporative emission rates are given in Table 3.25. The results of these calculations are summarized as follows:

Model Year	Evap. (gm/mile)	Var (evap.)
Pre-1971	2.99	0.0249
1971	0.49	0.000938
Post-1971	0.16	0.000100

Uncontrolled crankcase emissions of HC from pre-1963 model-year automobiles are calculated by the following equation:[37]

$$1.1\ \frac{\text{cu ft}}{\text{min}} \times 60\ \frac{\text{min}}{} \times 86\ \frac{\text{lb}}{\text{mole hex}} \times \frac{\text{1 mole air}}{\text{379 cu ft}} \times \frac{\text{15000 mole hex}}{10^6\ \text{mole air}}$$

$$\times \frac{\text{1 hr}}{\text{25 mi}} \times 454\ \frac{\text{gm}}{\text{lb}} = 4.08\ \frac{\text{gm}}{\text{vehicle mile}}$$

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Table 3.25 EVAPORATIVE EMISSIONS FROM LDG

77.8 gm/mile — $S\hat{y} = 3.27$

36.5 gm/ HEW test — $Sy = 1.22$

26 miles/day — Precision = 3.2%

Pre-1971

$$\text{evap} = 77.8\ \frac{\text{gm}}{\text{day}} \div 26\ \frac{\text{mi}}{\text{day}} = 2.99\ \frac{\text{gm}}{\text{mile}}$$

$$\text{Var(evap)} = h^2\left[\left(\frac{S\hat{y}_{\text{day}}}{y_{\text{day}}}\right)^2 + \left(\frac{P_{\text{mi}}}{\text{day}}\right)^2\right] = (2.99)^2\left[\left(\frac{3.27}{77.8}\right)^2 + (0.032)^2\right]$$

$$\text{Var(evap)} = 0.0249$$

1971

$$\text{evap} = \frac{77.8\ \text{gm/day}}{36.5\ \text{gm/HEW test}} \times 6\ \frac{\text{gm}}{\text{test}} \div 26\ \frac{\text{mi}}{\text{day}} = 0.49\ \frac{\text{gm}}{\text{mile}}$$

$$\text{Var(evap)} = h^2\left[\left(\frac{S\hat{y}_{\text{day}}}{y_{\text{day}}}\right)^2 + \left(\frac{S\hat{y}_{\text{test}}}{y_{\text{test}}}\right)^2 + \left(\frac{P_{\text{mi}}}{\text{day}}\right)^2\right] = (0.49)^2\left[\left(\frac{3.27}{77.8}\right)^2 + \left(\frac{1.22}{36.5}\right)^2 + (0.032)^2\right]$$

$$\text{Var(evap)} = 0.000938$$

Post-1971

$$\text{evap} = \frac{77.8\ \text{gm/day}}{36.5\ \text{gm/HEW test}} \times 2\ \frac{\text{gm}}{\text{test}} \div 26\ \frac{\text{mi}}{\text{day}} = 0.16\ \frac{\text{gm}}{\text{mile}}$$

$$\text{Var(evap)} = h^2\left[\left(\frac{S\hat{y}_{\text{day}}}{y_{\text{day}}}\right)^2 + \left(\frac{S\hat{y}_{\text{test}}}{y_{\text{test}}}\right)^2 + \left(\frac{P_{\text{mi}}}{\text{day}}\right)^2\right] = (0.16)^2\left[\left(\frac{3.27}{77.8}\right)^2 + \left(\frac{1.22}{36.5}\right)^2 + (0.032)^2\right]$$

$$\text{Var(evap)} = 0.000100$$

The factors in this equation that affect precision are the average blowby of 1.1 cfm and the average HC concentraton of 15,000 ppm. The other factors in the equation do not affect precision.

The average blowby flow rate and its standard deviation are reported by EPA in Reference 37. Upon examining the data in the reference, we interpret the reported standard deviation to be the standard deviation of the mean, $S_{\bar{x}}$. The reported value of $S_{\bar{x}}$ is 0.113 cfm. Precision of the blowby flow rate is therefore:

$$\text{Precision}_{\text{blowby flow rate}} = \frac{S_{\bar{x}}}{\bar{x}} = \frac{0.113\ \text{cfm}}{1.1\ \text{cfm}} = 0.103$$

The average HC concentration in blowby gases is given in a report of Scott Research Laboratories.[38] By use of data in this reference and the equations:

$$S_x = \frac{\text{Max} - \text{Min}}{d_2} \quad \text{and } S_{\bar{x}} = \frac{S_{\bar{x}}}{n}$$

the standard deviation of the mean, $S_{\bar{x}}$ is calculated to be 746 ppm. These calculations are shown in Table 3.26. Precision is then calculated as:

$$\text{Precision}_{\text{HC concentration}} = \frac{S_{\bar{x}}}{\bar{x}} = \frac{746}{15000} = 0.0497$$

The variance of the uncontrolled crankcase emission rate is then calculated by the equation:

$$\text{Var}(y) = y^2 \left[(\text{Precision}_{\text{blowby}})^2 + (\text{Precision}_{\text{HC concentration}})^2\right]$$
$$= (4.08)^2 \left[(0.103)^2 + (0.0497)^2\right] = 0.218$$

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Table 3.26 CONCENTRATION OF HC IN AUTOMOTIVE BLOWBY GASES

Total HC by FI, ppm (as Hexane)[a]
15,000
16,900
16,200
13,000
16,000

$$S_x = \frac{\text{Max} - \text{Min}}{d_2}$$

$$S_x = 1670$$

$$S_{\bar{x}} = \frac{S_x}{n}$$

$$S_{\bar{x}} = 746$$

a) Data from Reference 38, page 11.

Crankcase emissions from vehicles of the 1963 through 1967 model years were controlled by devices considered to be 80 percent effective.[37] The emission rates for those models are calculated by reducing the uncontrolled rate by 80 percent; the controlled emission rate therefore is 0.816 gm/mile. We estimate that the precision of the controlled emission rate equals the precision of the uncontrolled emission rate. Thus:

$$\frac{\mathrm{Var}(y_1)}{(y_1)^2} = \frac{\mathrm{Var}(y_2)}{(y_2)^2}$$

and the variance of the controlled rate is:

$$\mathrm{Var}\ (\text{controlled}) = (0.0131)(0.816)^2 = 0.00872$$

The crankcase emission controls for post-1967 model year automobiles are considered 100 percent effective, and emissions are therefore zero. Precision and variance are also considered to be zero for the post-1967 model vehicles.

Calculations for variance of the crankcase emission rates are summarized as follows:

Model Year	Crankcase Emissions (gm/mile)	Variance of Crankcase Emissions
Pre-1963	4.08	0.218
1963 thru 1967	0.816	0.00872
Post-1967	0	0

The individual emission rates for evaporative and crankcase emissions are added to give the combined emission rate, h. The variance of the combined rate is the sum of the variances of the components, as shown below:

Model year	Evaporative emission rate	Var(evap)	Crankcase emission rate	Var (crank)	Combined crankcase and evaporative emission rate, h	Var(h)
Pre-1963	3.0	0.0249	4.1	0.218	7.1	0.243
1963 thru 1967	3.0	0.0249	0.8	0.0087	3.8	0.0336
1968 thru 1970	3.0	0.0249	0	0	3.0	0.0249
1971	0.5	0.00094	0	0	0.5	0.00094
Post-1971	0.2	0.00010	0	0	0.2	0.00010

3.3.1.7 Combined Evaporative and Crankcase Emission Factor, f_n - The factor for combined evaporative and crankcase emissions is calculated by the equation presented earlier:

$$F_n = \Sigma h_i m_i$$

The variance of this emission factor is calculated by the following equations:

$$\mathrm{Var}(f_i) = f_i^{\,2} \left[\frac{\mathrm{Var}(h_i)}{(h_i)^2} + \frac{\mathrm{Var}(m_i)}{(m_i)^2} \right]$$

$$\text{and } \mathrm{Var}(f_n) = \mathrm{Var}(f_i)$$

Calculation of the variance of the combined evaporative and crankcase emission factor is shown in Table 3.27.

3.3.1.8 Total HC Emission Factor Exhaust and Combined Evaporative and Crankcase Emissions - The HC emission factors used in computer calculations are the sum of the exhaust emission factors (e_{HC}) and the combined evaporative and crankcase emission factors (f). The variance of the total HC emission factors therefore is the sum of variances of the exhaust factor and the combined evaporative and crankcase emission factors,

Table 3.27 LIGHT-DUTY GASOLINE-POWERED VEHICLES EVAPORATIVE AND CRANKCASE HYDROCARBON EMISSIONS; ALL ROAD TYPES

Age	Model year	Evap. & crankcase emission rate, h_i			Weighted annual travel, m_i			Evap. & crankcase emission factor, f_i		
		h_i	$Var(h_i)$	$\frac{Var(h_i)}{(h_i)^2}$	m_i	$Var(m_i)$	$\frac{Var(m_i)}{(m_i)^2}$	f_i	$Var(f_n)$	$\Sigma \frac{Var(x)}{x^2}$
1	1973	0.2	0.00010	0.00250	0.107	0.0000281	0.00245	0.0214	0.000002	0.00495
2	1972	0.2	0.00010	0.00250	0.151	0.0000477	0.00209	0.0302	0.000004	0.00459
3	1971	0.5	0.00094	0.00376	0.133	0.0000315	0.00178	0.0665	0.000024	0.00554
4	1970	3.0	0.0249	0.00277	0.111	0.0000198	0.00161	0.333	0.000486	0.00438
5	1969	3.0	0.0249	0.00277	0.112	0.0000177	0.00141	0.336	0.000472	0.00418
6	1968	3.0	0.0249	0.00277	0.104	0.0000160	0.00148	0.312	0.000414	0.00425
7	1967	3.8	0.0336	0.00233	0.078	0.0000116	0.00191	0.296	0.000371	0.00424
8	1966	3.8	0.0336	0.00233	0.063	0.0000117	0.00295	0.239	0.000302	0.00528
9	1965	3.8	0.0336	0.00233	0.046	0.0000095	0.00449	0.175	0.000209	0.00682
10	1964	3.8	0.0336	0.00233	0.027	0.0000055	0.00754	0.103	0.000105	0.00987
11	1963	3.8	0.0336	0.00233	0.020	0.0000051	0.01275	0.0760	0.000087	0.01508
12	1962	7.1	0.243	0.00482	0.012	0.0000024	0.01667	0.0852	0.000156	0.02149
≥13	1961 & older	7.1	0.243	0.00482	0.036	0.0000280	0.02160	0.256	0.001731	0.02642
								$\Sigma = 2.33$	$\Sigma = 0.00436$	

$f_i = h_i m_i$

$f_n = \Sigma f_i$

$$Var(f_i) = f_i^2 \left[\frac{Var(h_i)}{(h_i)^2} + \frac{Var(m_i)}{(m_i)^2}\right]$$

$Var(f_n) = \Sigma Var(f_i)$

$\sigma f_n = [Var(f_n)]^{1/2}$

$Var(f_n) = 0.00436$

$f_n = 2.33$

$$\text{Var(total HC emission factor)} = \text{Var}(e_{HC}) + \text{Var}(f)$$

The precision of the total HC factor is then:

$$\text{Precision} = \frac{\text{Var(total HC emission factor)}}{(e_{HC} + f)^2}^{1/2}$$

Table 3.28 shows the precision of the total HC emission factors.

3.3.2 Heavy-Duty, Gasoline-Powered Highway Vehicles

The procedures for calculating emission factors for heavy-duty gasoline-powered highway vehicles (HDG) are presented in Section 3.1.4 of AP-42. The HDG exhaust emission factors for CO, HC, and NO_x are calculated using the expression:

$$e_{np} = \sum_{i=n-12}^{n+1} c_i d_i m_i s_i$$

where e_{np} = Emission factor in grams per vehicle mile (g/km) for calendar year (n) and pollutant (p)

c_i = The test procedure emission rate (Table 3.1.4-1) for pollutant (p) in g/mi for the ith model year, at low mileage

d_i = The controlled vehicle pollutant (p) emission deterioration factor for the ith model year at calendar year (n)

m_i = The weighted annual travel of the ith model year vehicles during calendar year (n). The determination of this variable involves the use of the vehicle year distribution

s_i = The weighted speed adjustment factor for the ith model year vehicles

Also, a combined evaporative and crankcase HC emission factor is calculated and added to the exhaust HC emission factor to give total HC emissions from HDG's. The following expression for calculating evaporative and crankcase HC emissions is presented in Section 3.1.4 of AP-42:

Table 3.28 PRECISION OF TOTAL HC EMISSION FACTORS FOR LDG

Road type	Ave. speed (mph)	Exhaust HC emission factor, e	Var(e)	Combined evap. and crankcase emission factor, f	Var(f)	Total HC emission factor e+f	Var(total)	Precision, P
Urban	25	4.64	0.0271	2.33	0.0044	6.97	0.0315	0.025
Suburban	35	3.63	0.0165	2.33	0.0044	5.96	0.0209	0.024
Rural	45	3.09	0.0120	2.33	0.0044	5.42	0.0164	0.024
Limited access	55	2.67	0.0089	2.33	0.0044	5.00	0.0133	0.023

where:

$$P = \left[\frac{\mathrm{Var(total)}}{(e + f)^2}\right]^{1/2}$$

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$$f_n = \sum_{i = n - 12}^{n + 1} h_i m_i$$

where: f_n = The combined evaporative and crankcase hydrocarbon emission factor for calendar year (n)

h_i = The combined evaporative and crankcase hydrocarbon emission rate for the ith model year. Emission factors for this source are: pre 1968, 8.2 g/mi (5.1 g/km); and 1968 and later vehicles, 3.0 g/mi (1.9 g/km). In California: 1964-1972, 3.0 g/mi (1.9 g/km); post-1972, 0.2 g/mi (0.1 g/km).

m_i = The weighted annual travel of the ith model year vehicle during calendar year (n)

To calculate the precision of the total HC emission factor, we first determine the precisions of c_i, d_i, m_i, s_i, and h_i.

3.3.2.1 Test Procedure Emission Rate, c_i - Exhaust emission factors for all areas except those of high altitudes and California are given in Table 3.1.4-1 of AP-42. These factors were calculated from data in References 39 through 44 of this report.

The pre-1970 emission rates are calculated from dynamometer test data that simulated on-the-road conditions.[39-41] The precision of these data therefore is the precision of pre-1970 emission rates. Data from References 39 and 40 are used in the precision calculations but not the data from Reference 41 which are not in usable form.

The means and standard deviations by vehicle class are calculated separately for the two data sources and then combined. The mean and standard deviation of the combined data are calculated according to these formulas:

$$\bar{x} = \frac{n_1\bar{x}_1 + n_2\bar{x}_2}{n_1 + n_2}$$

$$S_p = \left[\frac{1}{n_1 + n_2 - 2} \left[(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2\right]\right]^{1/2}$$

$$S_{\bar{x}} = \frac{S_p}{\sqrt{n_1 + n_2}}$$

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Emissions of the three vehicle classes (combined data) are averaged into one emission rate for all trucks. Because a straight average would not realistically reflect the national truck population, the following weighting factors are used to combine the three vehicle classes. These data are from the 1967 Census of Transporation (Reference 45):

Vehicle class (Gross vehicle weight)	Number of trucks	Percent of total
II (6,001 to 10,000 lb. GVW)	11,318,000	73.7
III (10,001 to 19,500 lb. GVW)	2,098,000	13.7
IV (19,501 lb. GVW and up)	1,944,000	12.6

The weighted average and weighted standard deviation are calculated from the following equations:

$$\text{Weighted average} = 0.737\ \bar{X}_{II} + 0.137\ \bar{X}_{III} + 0.126\ \bar{X}_{IV}$$

$$S_{\bar{X}_{AVE}} = [(0.737)^2 (S_{\bar{X}_{II}})^2 + (0.137)^2 (S_{\bar{X}_{III}})^2 + (0.126)^2 (S_{\bar{X}_{IV}})^2]^{1/2}$$

These calculations and calculations of variance are given in Tables 3.29, 3.30, and 3.31 for pre-1970 emission rates of CO, HC, and NO_x, respectively.

Emission factors for 1970 through 1973 trucks were compiled from References 39 through 44 of this report. The emission rates are based on both dynamometer and on-the-road testing. References 42 and 43 are the sources for calculation of emission rates.

The dynamometer emission test data are given in Reference

Table 3.2 VARIANCE OF CO EMISSION RATES: PRE-1970 GASOLINE TRUCKS

Vehicle class	Ethyl Corp. (3.1.4-6, Ref.1)			SWRI (3.1.4-6, Ref. 2)			Average			
	n_1	Chassis dyndata CO/CO_2 scale (gm/mi) $(\bar{x}_i)$	S_1	n_2	Emissions $\bar{x}_2$ (gm/mi)	S_2	n_1+n_2	$\bar{x}$	S_p	$\sigma_{\bar{x}}$
II	20	104	28.6	30	154	41.9	50	134	37.2	5.26
III	20	144	43.2	47	183	47.7	67	171	46.4	5.67
IV	20	138	54.6	57	162	63.1	77	156	61.1	6.96

Where $\bar{x} = \dfrac{n_1\bar{x}_1 + n_2\bar{x}_2}{n_1 + n_2}$

$$S_p = \left\{\frac{1}{n_1+n_2-2}\left[(n_1-1)S_1^{\,2} + (n_2-1)S_2^{\,2}\right]\right\}$$

$$\sigma_{\bar{x}} = \frac{S_p}{\sqrt{n_1+n_2}}$$

Weighted Average

	Emissions (gm/mi)	STD. deviation	Var(C)	$\dfrac{Var(C)}{C^2}$
Calculated	142	4.05	16.4	.00081
AP-42	140		15.9*	.00081

$$\text{WT. Average} = .737\bar{x}_{II} + .137\bar{x}_{III} + .126\bar{x}_{IV}$$

$$\text{ave} = \left[(.737)^2(\sigma_{\bar{x}_{II}})^2 + (.137)^2(\sigma_{\bar{x}_{III}})^2 + (.126)^2(\sigma_{\bar{x}_{IV}})^2\right]^{1/2}$$

* where $\dfrac{Var(C_1)}{(C_1)^2} = \dfrac{Var(C_2)}{(C_2)^2}$

Table 3.30 VARIANCE OF EXHAUST H EMISSION RATES: PRE-1970 GASOLINE TRUCK

Vehicle class	Ethyl Corp. (3.1.4-6, Ref.1)			SWRI (3.1.4-6, Ref. 2)			Average			
	n_1	Chassis dyndata CO/CO$_2$ scale (gm/mi) ($\bar{x}_i$)	S_1	n_2	Emissions $\bar{x}_2$ (gm/mi)	S_2	n_1+n_2	$\bar{x}$	S_p	$\sigma_{\bar{x}}$
II	20	19.8	3.63	30	34.4	7.63	50	22.6	6.36	0.899
III	20	25.7	12.2	47	21.3	7.04	67	22.6	8.86	1.06
IV	20	24.6	9.03	57	21.8	9.85	77	22.5	7.65	1.10

Where $\bar{x} = \dfrac{n_1\bar{x}_1 + n_2\bar{x}_2}{n_1 + n_2}$

$$S_p = \left\{\frac{1}{n_1+n_2-2}\left[(n_1-1)S_1^2 + (n_2-1)S_2^2\right]\right\}$$

$$\sigma_{\bar{x}} = \frac{S_p}{\sqrt{n_1+n_2}}$$

Weighted Average

	Emissions (gm/mi)	STD. deviation	Var(C)	$\dfrac{\mathrm{Var(C)}}{C^2}$
Calculated	22.6	0.692	0.479	.00094
AP-42	17		0.272*	.00094

WT. Average $= .737\bar{x}_{II} + .137\bar{x}_{III} + .126\bar{x}_{IV}$

ave $= \left[(.737)^2(\sigma_{\bar{x}_{II}})^2 + (.137)^2(\sigma_{\bar{x}_{III}})^2 + (.126)^2(\sigma_{\bar{x}_{IV}})^2\right]^{1/2}$

* where $\dfrac{\mathrm{Var}(C_1)}{(C_1)^2} = \dfrac{\mathrm{Var}(C_2)}{(C_2)^2}$

Table 3.31 VARIANCE OF NO_x EMISSION RATES: PRE-1970 GASOLINE TRUCKS

Vehicle class	Ethyl Corp. (3.1.4-6, Ref.1)			SWRI (3.1.4-6, Ref. 2)			Average			
	n_1	Chassis dyndata CO/CO_2 scale (gm/mi) ($\bar{x}_1$)	S_1	n_2	Emissions $\bar{x}_2$ (gm/mi)	S_2	n_1+n_2	$\bar{x}$	S_p	$\sigma_{\bar{x}}$
II	20	6.36	2.54	30	6.31	2.19	50	6.33	2.33	0.330
III	20	15.5	6.63	47	7.40	3.04	67	9.82	4.40	0.538
IV	20	21.0	6.58	57	7.72	3.30	77	11.2	4.37	0.498

Where $\bar{x} = \dfrac{n_1\bar{x}_1 + n_2\bar{x}_2}{n_1 + n_2}$

$$S_p = \left\{\frac{1}{n_1+n_2-2}\left[(n_1-1)S_1^2 + (n_2-1)S_2^2\right]\right\}$$

$$\sigma_{\bar{x}} = \frac{S_p}{\sqrt{n_1+n_2}}$$

Weighted Average

	Emissions (gm/mi)	STD. deviation	Var(C)	$\frac{Var(C)}{C^2}$
Calculated	7.42	0.262	.0686	.00125
AP-42	9.4		0.110*	.00125

$$\text{WT. Average} = .737\bar{x}_{II} + .137\bar{x}_{III} + .126\bar{x}_{IV}$$

$$\text{ave} = \left[(.737)^2(\sigma_{\bar{x}_{II}})^2 + (.137)^2(\sigma_{\bar{x}_{III}})^2 + (.126)^2(\sigma_{\bar{x}_{IV}})^2\right]^{1/2}$$

* where $\dfrac{Var(C_1)}{(C_1)^2} = \dfrac{Var(C_2)}{(C_2)^2}$

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43 in terms of grams of pollutant per pound of fuel. To convert to road emissions in units of grams of pollutants per mile traveled, the rate for gm/lb of fuel is divided by a dynamometer-to-road emission correction factor, multiplied by a fuel density factor, and divided by an average mile per gallon factor. The precision of the value for road emissions in grams per mile is determined by the precision of the factors with which the value is calculated. Standard deviations of the emission test data in grams per pound of fuel are presented in Tables 3.32, 3.33, and 3.34 for CO, HC, and NO_x respectively. The miles per gallon figure and dynamometer-to-road correction factors for HC, CO, and NO_x are based on test data in Reference 42. Standard deviations of these data are given in Table 3.35.

The emission rate is then calculated using the following equation:

$$\text{Emissions, } C = \frac{\text{lb}}{\text{lb of fuel}} \times \frac{1}{\text{Dyn/Road Correction}} \times \frac{\text{lb fuel}}{\text{gal}} \times \frac{1}{\text{MPG}}$$

In this equation, the lb fuel/gallon factor is considered precise and therefore is not used in calculation of precision of the emission rate. The variance of the AP-42 emission rates for 1970-1973 models is then calculated using the calculated variance and the relationship:

$$\frac{\text{Var } (C_1)}{(C_1)^2} = \frac{\text{Var } (C_2)}{(C_2)^2}$$

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Table 3.32 VARIANCE OF CO EMISSION RATES: 1970-73 GASOLINE TRUCKS

Vehicle class	$\frac{\text{Grams}}{\text{lb of fuel}}$	σ	n	$\frac{\sigma}{n} = \sigma_{\bar{x}}$	Percent of total[a]
II	96.7	35.1	58	4.61	73.7
III	63.2	29.5	20	6.60	13.7
IV	107.5	40.5	67	4.95	12.6

Where $\sigma = \left[\frac{n(\Sigma x^2) - (\Sigma x)^2}{n(n-1)}\right]$

Weighted average

$$96.7 \times 0.737 + 63.2 \times 0.137 + 108 \times 0.126 = 71.3 + 8.7 + 13.6$$

Wt. Average = 93.6 grams/lb of fuel

$$\sigma_{\bar{x}} \text{ ave} = \left[(0.737)^2(\sigma_{\bar{x}_{II}})^2 + (0.137)^2(\sigma_{\bar{x}_{III}})^2 + (0.126)^2(\sigma_{\bar{x}_{IV}})^2\right]$$

$$\left[(0.737)^2(4.61)^2 + (0.137)^2(6.60)^2 + (0.126)^2(4.95)^2\right]$$

$$= 3.57 \text{ g/mi}$$

[a] Section 3.1.4-6, Reference 44.

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Table 3.33 VARIANCE OF EXHAUST HC EMISSION RATES:
1970-73 GASOLINE TRUCKS

Vehicle class	$\frac{\text{Grams}}{\text{lb of fuel}}$	σ	n	$\frac{\sigma}{n} = \sigma_{\bar{x}}$	Percent of total
II	9.99	2.41	58	0.316	
III	9.31	1.98	20	0.443	
IV	12.44	6.05	67	0.983	

Where $\sigma = \left[\frac{n(\Sigma x^2) - (\Sigma x)^2}{n(n-1)}\right]$

Weighted average

$$9.99 \times 0.737 + 9.31 \times 0.137 + 12.44 \times 0.126 = 7.36 + 1.28 + 1.57$$

Wt. Average = 10.21 grams/lb of fuel

$$\sigma_{\bar{x}} \text{ ave} = \left[(0.737)^2(\sigma_{\bar{x}_{II}})^2 + (0.137)^2(\sigma_{\bar{x}_{III}})^2 + (0.126)^2(\sigma_{\bar{x}_{IV}})^2\right]$$

$$\left[(0.737)^2(.316)^2 + (0.137)^2(0.443)^2 + (0.126)^2(.983)^2\right]$$

$$= 0.271 \text{ g/mi}$$

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Table 3.34 VARIANCE OF NO_x EMISSION RATES:
1970-73 GASOLINE TRUCKS

Vehicle class	Grams / lb of fuel	σ	n	$\frac{\sigma}{n} = \sigma_{\bar{x}}$	Percent of total
II	14.23	6.63	58	0.871	
III	18.67	5.38	20	1.00	
IV	11.25	5.16	67	0.63	

Where $\sigma = \left[\frac{n(\Sigma x^2) - (\Sigma x)^2}{n(n-1)}\right]$

Weighted average

$$14.23 \times 0.737 + 18.67 \times 0.137 + 11.25 \times 0.126 = 10.49 + 2.56 + 1.42$$

Wt. Average = 14.47 grams/lb of fuel

$$\sigma_{\bar{x}} \text{ ave} = \left[(0.737)^2(\sigma_{\bar{x}_{II}})^2 + (0.137)^2(\sigma_{\bar{x}_{III}})^2 + (0.126)^2(\sigma_{\bar{x}_{IV}})^2\right]$$

$$\left[(0.737)^2(.871)^2 + (0.137)^2(1.20)^2 + (0.126)^2(0.63)^2\right]$$

$$= 0.667 \text{ g/mi}$$

Table 3.35 STANDARD DEVIATIONS OF DATA IN REFERENCE 41

		Average	$S_{\bar{x}}$
Miles per gallon		5.77	0.228
Dynamometer/road correction factor			
	HC	0.85	0.0439
	CO	0.68	0.0633
	NO_x	1.22	0.0616

Where:

$$S_{\bar{x}} = \frac{\text{standard deviation}}{\sqrt{n}}$$

Calculations of variance of the AP-42 emission rates for 1970-1973 model trucks are shown in Table 3.36.

3.3.2.2 Deterioration Factor, d_i - Deterioration factors for HDG apply only to 1975 and later California vehicles. The deterioration factor for all other HDG is 1. Therefore, the deterioration factor used in this report for HDG calculations is one and the precision of this factor is zero.

3.3.2.3 Weighted Annual Travel, m_i - The factors for weighted annual travel, m_i, are given in Table 3.1.4-3 of AP-42. These factors were calculated by the formula $m = \frac{ab}{\Sigma ab}$, where a is the fraction of total vehicles in use nationwide (by vehicle age) and b is the average annual miles driven (also by vehicle age). The precision of m_i, then, depends upon the precision of both the fraction of vehicles in use and the average annual miles driven.

The fraction of vehicles in use nationwide is obtained from 1971 Motor Truck Facts.[46] These numbers are very precise, since they are obtained from nationwide registration figures. Calculations of truck emissions for any jurisdiction within the United States could use registration data from that jurisdiction in lieu of the nationwide figures to determine the fraction of vehicles in use. Precision would be the same, since both calculations are based on registration data. The precision value would be very low, since registration data are very precise. Therefore the precision of the value for fraction of vehicles in use is not used in calculating precision of the annual travel value.

Table 3.36 VARIANCE OF THE EMISSION RATE FROM 1970-1973 MODEL GASOLINE TRUCKS

Pollutant	Emissions, g gm/lb of fuel			Dynamometer correction, γ			Conversion factor, $\frac{\text{lb fuel}}{\text{gal}}$	Miles per gallon			Calculated emission rate		
	g	$\sigma_{\bar{g}}$	$\frac{\text{Var}(g)}{(g)^2}$	$\frac{1}{\gamma}$	$\sigma_{\bar{\gamma}}$	$\frac{\text{Var}(\gamma)}{(\gamma)^2}$		$\frac{1}{\text{mpg}}$	$\sigma_{\overline{\text{mpg}}}$	$\frac{\text{Var(mpg)}}{(\text{mpg})^2}$	C_1	$\Sigma\frac{\text{Var}(x)}{x^2}$	$\text{Var}(C_1)$
CO	93.6	3.57	.00145	$\frac{1}{0.68}$	.0633	.00867	6.24	$\frac{1}{6.21}$	0.228	.00135	138	.01147	218
HC (exhaust)	10.21	0.271	.00070	$\frac{1}{0.85}$	.0439	.00267	6.24	$\frac{1}{6.21}$	0.228	.00135	12.1	.00472	0.691
NO_x	14.47	0.667	.00212	$\frac{1}{1.22}$	.0616	.00255	6.24	$\frac{1}{6.21}$	0.228	.00135	11.9	.00602	0.852

where:

$$C_1\left[\frac{gm}{mi}\right] = g \times \frac{1}{\gamma} \times \frac{\text{lb fuel}}{\text{gal}} \times \frac{1}{\text{mpg}}$$

$$\frac{\text{Var}(x)}{(x)^2} = \left(\frac{\sigma_{\bar{x}}}{x}\right)^2$$

$$\text{Var}(C_1) = (C_1)^2\left[\left(\frac{\sigma_{\bar{g}}}{g}\right)^2 + \left(\frac{\sigma_{\bar{\gamma}}}{\gamma}\right)^2 + \left(\frac{\sigma_{\overline{\text{mpg}}}}{\text{mpg}}\right)^2\right]$$

Pollutant	AP-42 Emission rate, C_2	$\text{Var}(C_2)$	$\frac{\text{Var}(C_2)}{(C_2)^2}$
CO	130	194	.01147
HC (exhaust)	16	1.21	.00472
NO_x	9.2	0.510	.00602

where:

$$\frac{\text{Var}(C_1)}{(C_1)^2} = \frac{\text{Var}(C_2)}{(C_2)^2}$$

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The 1967 Census of Transportation[45] is the source of data on average miles per truck. The value for average miles per truck is computed by dividing annual truck miles (according to year model) by the corresponding number of trucks. The reference provides data on the sampling variability of the number of trucks, but not for the truck miles or precision of average miles per truck. However, the Census reports that the sampling variability of values for truck-miles is larger than the variability shown for the corresponding estimate of the number of trucks. Since it is not possible to determine the magnitude of the difference in variability, the variability of the truck-miles figure is assumed to be equal to the variability of the number of trucks. Therefore the variance of the annual miles driven is:

$$\text{Var (b)} = b^2 \left[\frac{s_t^{\,2}}{t^2} + \frac{s_m^{\,2}}{m^2} \right]$$

where $b = \frac{t}{m}$, average annual miles driven

t = number of trucks

m = truck miles

Since the precision of truck miles is assumed to equal the precision of number of trucks, the equation reduces to:

$$\text{Var (b)} = b^2 \left[2 \times \frac{s_t^{\,2}}{t^2} \right]$$

The variance and precision of values for average annual miles driven are given in Table 3.37.

The variance of the weighted annual travel, Var (m_i), is then calculated:

Table 3.37 VARIANCE OF AVERAGE ANNUAL MILES

Age	Year model	Percent of total trucks	Sampling variability (percent)	$\frac{\sigma \bar{x}}{\bar{x}}$	Precision = $\left(\frac{\sigma \bar{x}}{\bar{x}}\right)^2$
1 and 2	1966 & '67	16.5	0.3	0.3/16.5	.00033
3 and 4	1964 & '65	18.7	0.2	0.2/18.7	.00011
5 to 8	1960 to'63	23.8	0.2	0.2/23.8	.00007
9 & older	Pre 1960	41.0	0.2	0.2/41.0	.00002

Assumed precision of number of trucks and truck miles were equal

Therefore: $Var(b) = b^2 [2 \times (\text{Precision of number of trucks})]$

Age	b	Precision of number of trucks	$\frac{Var(b)}{(b)^2}$	Var(b)
1 and 2	17,200	.00033	.00066	195,254
3 and 4	15,800	.00011	.00022	54,921
5 and 6	13,000	.00007	.00014	23,660
7 and 8	11,000	.00007	.00014	16,940
9 and 10	9,000	.00002	.00004	3,240
11 & older	5,500	.00002	.00004	1,210

$$Var(b) = b^2 \left[\frac{\sigma T^2}{T^2} + \frac{\sigma m^2}{m^2}\right]$$

T = number of trucks

m = truck miles

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$$\mathrm{Var}(m_i) = m_i^2 \left[\frac{\mathrm{Var}(a_i b_i)}{(a_i b_i)^2} + \frac{\mathrm{Var}(\Sigma a_i b_i)}{(\Sigma a_i b_i)^2} \right]$$

Table 3.38 shows the calculation of $\mathrm{Var}(m_i)$.

3.3.2.4 Weighted Speed Adjustment Factor, s_i - The speed adjustment factors for LDG are also used for HDG. This affects the accuracy of HDG emission values but the precision of the speed adjustment factors remain the same. The section on LDG speed correction factors gives details of the calculations, which yield the following:

Pollutant	Precision	$\frac{\mathrm{Var}(S_i)}{(S_i)^2}$
HC	0.0396	0.00157
CO	0.0670	0.00449
Ave = NO_x	0.0533	0.00303

3.3.2.5 Total Exhaust Emissions, e_n - The total HDG exhaust emissions, e_n, and their precisions are calculated as follows:

$$e_i = c_i d_i m_i s_i$$

$$e_n = \Sigma e_i$$

$$\mathrm{Var}(e_i) = (e_i)^2 \left[\frac{\mathrm{Var}(C_i)}{(C_i)^2} + \frac{\mathrm{Var}(d_i)}{(d_i)^2} + \frac{\mathrm{Var}(m_i)}{(m_i)^2} + \frac{\mathrm{Var}(s_i)}{(s_i)^2} \right]$$

$$\mathrm{Var}(e_n) = \Sigma \mathrm{Var}(e_i)$$

Standard Deviation, $S_{e_n} = [\mathrm{Var}(e_n)]^{1/2}$

$$\text{Precision} = \frac{S_{e_n}}{e_n}$$

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Table 3.38 VARIANCE OF WEIGHTED ANNUAL TRAVEL, $Var(m_i)$ FOR GASOLINE TRUCKS

Age	Fract. in use (a)	Ave. travel (b)	a x b	$\frac{Var(b)}{(b)^2} = \frac{Var(ab)}{(ab)^2}$	Var(ab)	m	$\frac{Var[\Sigma(ab)]}{[\Sigma(ab)]^2}$	$\frac{Var(m)}{(m)^2}$	Var(m)
0	0.000	17,200	0	.00066	0	0.000	0	0	0
1	.071	17,200	1221	.00066	984	.107	.00003	.00069	78×10^{-7}
2	.106	17,200	1823	.00066	2193	.159	.00003	.00069	174×10^{-7}
3	.087	15,800	1375	.00022	416	.120	.00003	.00025	36×10^{-7}
4	.081	15,800	1280	.00022	363	.112	.00003	.00025	31×10^{-7}
5	.084	13,000	1090	.00014	166	.095	.00003	.00017	15×10^{-7}
6	.076	13,000	988	.00014	137	.086	.00003	.00017	17×10^{-7}
7	.065	11,000	715	.00014	72	.062	.00003	.00017	6×10^{-7}
8	.055	11,000	605	.00014	51	.052	.00003	.00017	4×10^{-7}
9	.047	9,000	423	.00004	7	.037	.00003	.00007	1×10^{-7}
10	.035	9,000	315	.00004	4	.028	.00003	.00007	$.5 \times 10^{-7}$
11	.037	5,500	204	.00004	2	.018	.00003	.00007	$.2 \times 10^{-7}$
12	.033	5,500	182	.00004	1	.016	.00003	.00007	$.2 \times 10^{-7}$
≥ 13	.223	5,500	1226	.00004	60	.108	.00003	.00007	8×10^{-7}
		TOTALS:	11447	.00318	4453				

Assumed variance of a is negligible because of the large sample (nationwide figures).

$$Var(ab) = (ab)^2 \left[\frac{Var(b)}{(b)^2}\right] \qquad \frac{Var(ab)}{(ab)^2} = \frac{Var(b)}{(b)^2}$$

$$Var\ (\Sigma ab) = \Sigma Var(ab)$$

$$\frac{Var(m_i)}{(m_i)^2} = \left[\frac{Var(ab)}{(ab)^2} + \frac{Var(\Sigma ab)}{(\Sigma ab)^2}\right]$$

Table 3.39 summarizes the precisions of the CO, HC, and NO_x exhaust emission factors for HDG's. Tables F-1 through F-4, Tables F-5 through F-8, and Tables F-9 through F-12, Appendix F, show respectively the calculations for precision of CO, HC, and NO_x factors.

It is emphasized again that these calculations show the precision of the emission factors but do not reflect their accuracy.

3.3.2.6 Combined Evaporative and Crankcase Emission Rate, h_i - The combined evaporative and crankcase emission rates for HDG's are presented on page 3.1.4-1 of AP-42. To determine the precision of the combined emission rate, we first calculate separately the precisions of both the evaporative and the crankcase emission rates.

Because no information is available concerning evaporative emissions from HDG vehicles, we assume that the rate is equal to the LDG uncontrolled rate of 2.99 grams/mile.[37] Although this assumption affects the accuracy of the HDG evaporation rate, the precision is the same as that for the uncontrolled LDG rate. The variance of the HDG evaporation rate, therefore, is 0.0249.

The crankcase emission rate for uncontrolled HDG's is calculated by multiplying the uncontrolled LDG emission rate (1.08 gm/mile) by the ratio of exhaust volumes (HDG/LDG).[37] This calculation gives a rate of 5.2 gm/mile.[36] Calculation of the precision of the HDG crankcase emission rate includes not only the precision of the LDG crankcase emission rate, but also the

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Table 3.39 PRECISION OF HEAVY-DUTY, GASOLINE-POWERED HIGHWAY VEHICLE EXHAUST EMISSION FACTORS

Road type	Precision $= \frac{\sigma e}{e}$		
	CO	Exhaust HC	NO_x
Urban	0.034	0.023	0.028
Suburban	0.034	0.023	0.028
Rural	0.035	0.023	0.028
Limited access	0.035	0.023	0.028

precisions of the HDG and LDG flow rates. Since the references give no data on determination of LDG and HDG exhaust volumes we estimate that the precision of each of the exhaust volumes equals the precision of the LDG blowby rate, which earlier was calculated as 0.103.

The variance of the HDG crankcase emission rate is calculated by the following equation:

$$\mathrm{Var}(\mathrm{HDG}_{\mathrm{crankcase}}) = (5.2)^2 \left[\frac{\mathrm{Var}(\mathrm{LDG}_{\mathrm{crankcase}})}{(4.08)^2} + 2(\mathrm{Precision}_{\mathrm{LDG\ flow\ rate}})^2 \right] = 0.927$$

Starting in 1968, all HDG were required to have controls that were 100 percent effective in eliminating crankcase emissions. Therefore, the values for crankcase emission rate and variances for 1968 and later HDG's are zero.

The combined crankcase and evaporative emission rates for HDG's, and their variances, are as follows:

Model Year	Evaporative Emission Rate	Var (evap)	Crankcase Emission Rate	Var (crank)	Combined Crankcase and Evaporative Emission Rate, h	Var(h)
Pre-1968	3.0	0.0249	5.2	0.927	8.2	0.952
1968 and later	3.0	0.0249	0	0	3.0	0.0249

3.3.2.7 Combined Evaporative and Crankcase Emission Factor, f_n - The combined evaporative and crankcase emission factor is calculated by the equation presented earlier:

$$f_n = \Sigma h_i m_i$$

The variance of the emission factor is calculated by the following equations:

$$\mathrm{Var}(f_i) = f_i^{\,2} \quad \frac{\mathrm{Var}(h_i)}{(h_i)^2} + \frac{\mathrm{Var}(m_i)}{(m_i)^2}$$

$$\text{and } \mathrm{Var}(f_n) \;=\; \mathrm{Var}(f_i)$$

Calculations of the variance of the combined evaporative and crankcase emission factor are shown in Table 3.40.

3.3.2.8 Total Exhaust and Combined Evaporation and Crankcase HC Emission Factors - The HC emission factors used in the computer calculations are the sum of the exhaust emission factors (e_{HC}) and the combined evaporative and crankcase emission factors (f). The variance of the total HC emission factors is therefore the sum of the variances of exhaust and combined evaporative and crankcase emission factors,

$$\mathrm{Var}(\text{total HC emission factor}) = \mathrm{Var}(e_{HC}) + \mathrm{Var}(f)$$

The precision of the total HC factor is then:

$$\text{Precision} \;=\; {\frac{\mathrm{Var}(\text{total HC emission factor})}{(e_{HC} + f)^2}}^{1/2}$$

Table 3.41 shows the precision of the total HC emission factor.

3.3.3 Heavy-Duty, Diesel-Powered Highway Vehicles

Emission factors for heavy-duty, diesel-powered highway vehicles (HDD) are given in Section 3.1.5 of AP-42. These emission factors apply to all HDD's regardless of vehicle speeds, geographical location, or vehicle age. The reference cited in AP-42 for calculation of the emission factors is a compilation

Table 3.40 HEAVY-DUTY, GASOLINE-POWERED VEHICLES EVAPORATIVE AND CRANKCASE HYDROCARBON EMISSIONS; ALL ROAD TYPES

Age	Model year	Evap. & crankcase emission rate, h_i			Weighted annual travel, m_i			Evap. & crankcase emission factor, f_i		
		h_i	$Var(h_i)$	$\frac{Var(h_i)}{(h_i)^2}$	m_i	$Var(m_i)$	$\frac{Var(m_i)}{(m_i)^2}$	f_i	$Var(f_n)$	$\Sigma \frac{Var(x)}{x^2}$
1	1973	3.0	0.0249	0.00277	0.107	78×10^{-7}	0.00069	0.321	0.00036	0.00346
2	1972	3.0	0.0249	0.00277	0.159	174×10^{-7}	0.00069	0.477	0.00079	0.00346
3	1971	3.0	0.0249	0.00277	0.120	36×10^{-7}	0.00025	0.360	0.00039	0.00302
4	1970	3.0	0.0249	0.00277	0.112	31×10^{-7}	0.00025	0.336	0.00034	0.00302
5	1969	3.0	0.0249	0.00277	0.095	15×10^{-7}	0.00017	0.285	0.00024	0.00294
6	1968	3.0	0.0249	0.01416	0.086	17×10^{-7}	0.00017	0.258	0.00020	0.00294
7	1967	8.2	0.0952	0.01416	0.062	6×10^{-7}	0.00017	0.508	0.00370	0.01433
8	1966	8.2	0.952	0.01416	0.052	4×10^{-7}	0.00017	0.426	0.00260	0.01433
9	1965	8.2	0.952	0.01416	0.037	1×10^{-7}	0.00007	0.303	0.00131	0.01423
10	1964	8.2	0.952	0.01416	0.028	0.5×10^{-7}	0.00007	0.230	0.00075	0.01423
11	1963	8.2	0.952	0.01416	0.018	0.2×10^{-7}	0.00007	0.118	0.00031	0.01423
12	1962	8.2	0.952	0.01416	0.016	0.2×10^{-7}	0.00007	0.131	0.00024	0.01423
≥13	1961 & older	8.2	0.952	0.01416	0.103	8×10^{-7}	0.00007	0.866	0.01117	0.01423
								$\Sigma=4.67$	$\Sigma=0.0224$	

$f_i = h_i m_i$

$f_n = \Sigma f_i$

$$Var(f_i) = f_i^2 \left[\frac{Var(h_i)}{(h_i)^2} + \frac{Var(m_i)}{(m_i)^2} \right]$$

$Var(f_n) = \Sigma Var(f_i)$

$\sigma f_n = [Var(f_n)]^{1/2}$

$Var(f_n) = 0.0224$

$f_n = 4.67$

Table 3.41 PRECISION OF TOTAL HC EMISSION FACTORS FOR HDG

Road type	Ave. speed (mph)	Exhaust HC emission factor, e	Var(e)	Combined evap. and crackcase emission factor, f	Var(f)	Total HC emission factor e+f	Var(total)	Precision, P
Urban	25	14.4	0.105	4.7	0.0224	19.1	0.127	0.019
Suburban	35	11.2	0.0644	4.7	0.0224	15.9	0.0868	0.019
Rural	45	9.6	0.0469	4.7	0.0224	14.3	0.0693	0.018
Limited access	55	8.3	0.0348	4.7	0.0224	13.0	0.0572	0.018

Where:

$$p = \left[\frac{\text{Var(total)}}{(e + f)^2}\right]^{1/2}$$

of data, that gives only derived emission factors.[47] Since the reference does not provide enough data from which to calculate the precision of the emission factors, we assume that the precision of the NO_x emission factor for HDD's is equal to the precision of the emission factor for uncontrolled (pre-1970) HDG's, which was earlier determined as:

$$\text{Precision} = \left[\frac{\text{Var}(C_i)}{(C_i)^2}\right]^{1/2} = 0.00125^{\,1/2} = 0.035$$

The precision of the NO_x emission factor for HDD's therefore is 0.035.

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